

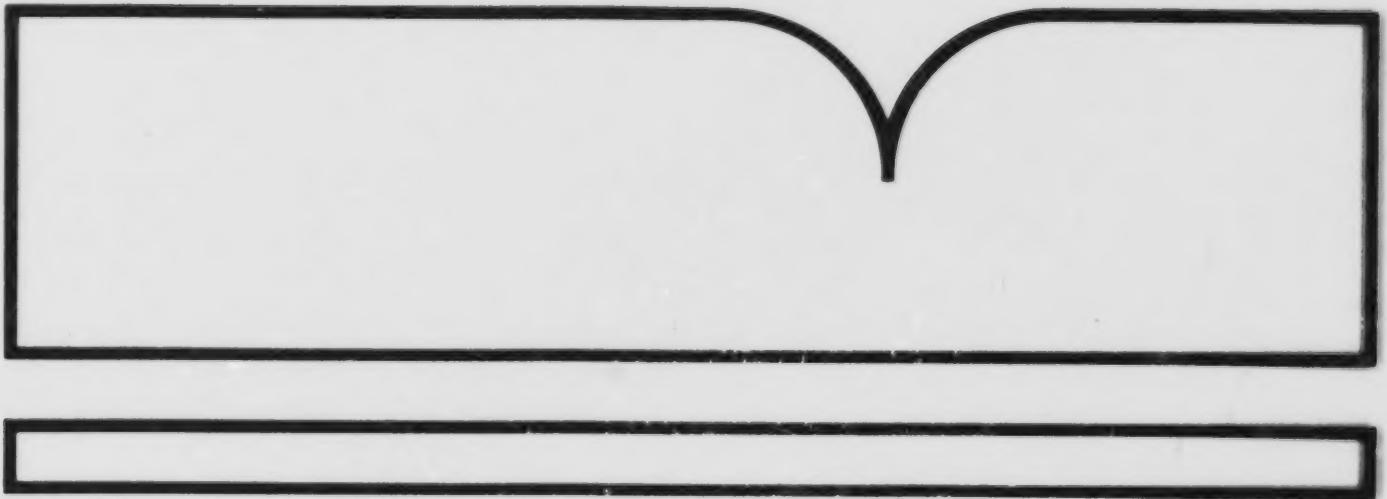
Assessment of Fluidized-Bed Combustion
Solid Wastes for Land Disposal. Volume 7
Appendix I

Radian Corp., Austin, TX

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Feb 85



PB85-175925

EPA/600/7-85/007g
February 1985

**ASSESSMENT OF
FLUIDIZED-BED COMBUSTION
SOLID WASTES FOR LAND DISPOSAL**

Volume 7. Appendix I

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EPA Contract No. 68-02-3103

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TECHNICAL REPORT DATA (Please read instructions on the reverse before completing)		
1. REPORT NO. EPA/600/7-85/007g	2.	3. RECIPIENT'S ACCESSION NO. PBB 5 175925/AS
4. TITLE AND SUBTITLE Assessment of Fluidized-bed Combustion Solid Wastes for Land Disposal, Volume 7. Appendix I	5. REPORT DATE February 1985	
6. PERFORMING ORGANIZATION CODE		7. AUTHOR(S) A.G. Eklund, T.W. Grimshaw, and R.A. Minear
8. PERFORMING ORGANIZATION REPORT NO.		9. PERFORMING ORGANIZATION NAME AND ADDRESS Radian Corporation P.O. Box 9948 Austin, Texas 78766
10. PROGRAM ELEMENT NO.		11. CONTRACT/GRANT NO. 68-02-3103
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 6/80 - 6/84
14. SPONSORING AGENCY CODE EPA/600/13		15. SUPPLEMENTARY NOTES AEERL project officer John O. Milliken is no longer with the Laboratory; for assistance contact Michael A. Maxwell, Mail Drop 61, 919/541-3091.
16. ABSTRACT The report, including 10 appendices, gives results of: (1) an analysis of representative samples of fluidized-bed combustion (FBC) wastes, (2) an assessment of the characteristics of leachates generated from the wastes under laboratory and field (landfill) conditions, (3) a characterization of the attenuation of the leachates by earth materials that are typical of disposal settings, (4) development of a way to predict the leachate generation behavior of FBC wastes under landfill conditions on the basis of laboratory test results by establishing a rigorous statistical relationship between the laboratory and field leaching results, and (5) assessment of the compatibility of commonly used landfill liner materials with FBC waste leachates. FBC is an emerging energy technology that holds promise for both high efficiency of energy conversion and minimization of adverse air quality impacts. A major advantage of FBC is that high-sulfur coal can be burned without the use of flue gas desulfurization equipment to meet air quality standards. The solid residues that are generated in an FBC unit are usually larger in volume and have different properties than the typical bottom ash from a conventional boiler.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field Group
Pollution Assessments	Pollution Control	13B 14B
Waste Disposal Desulfurization	Stationary Sources	07A, 07D
Combustion Earth Fills		21B 13C
Fluidized Bed Linings		11G
Processing Sorbents		13H
Coal		21D
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 143
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Abstract

The report, including 10 appendices, gives results of: (1) an analysis of representative samples of fluidized-bed combustion (FBC) wastes, (2) an assessment of the characteristics of leachates generated from the wastes under laboratory and field (landfill) conditions, (3) a characterization of the attenuation of the leachates by earth materials that are typical of disposal settings, (4) development of a way to predict the leachate generation behavior of FBC wastes under landfill conditions on the basis of laboratory test results by establishing a rigorous statistical relationship between the laboratory and field leaching results, and (5) assessment of the compatibility of commonly used landfill liner materials with FBC waste leachates. FBC is an emerging energy technology that holds promise for both high efficiency of energy conversion and minimization of adverse air quality impacts. A major advantage of FBC is that high-sulfur coal can be burned without the use of flue gas desulfurization equipment to meet air quality standards. The solid residues that are generated in an FBC unit are usually larger in volume and have different properties than the typical bottom ash from a conventional boiler.

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Appendix I

INTERPRETATION OF CHEMICAL TRENDS AND
COMPARISON OF LEACHATE COMPOSITION WITH
WATER QUALITY STANDARDS AND CRITERIA

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I.1 Overview

The foregoing appendices form the basis for additional interpretation of the chemical trends that occurred in the laboratory and field investigations. This appendix presents a qualitative description of the types of chemical mechanisms and associated behavior trends during leachate generation and attenuation. Concentration trends observed during the leachate generation phase of each component of the investigation are categorized, and possible chemical mechanisms are advanced to explain the observed behavior in each category. Also for the leaching results, an evaluation is made of solubility control by using a computer model for chemical equilibrium assessment. A summary description of concentration ranges observed during waste and disposal media leaching is then presented for each element and species, and a comparison is made of the ranges observed for each of the three FBC wastes and six disposal media studied.

A categorization of observed concentration trends during the attenuation/mobilization phases of the investigation is also presented with possible chemical mechanisms which might account for the observed behavior. Finally, a comparison is made between the concentration of each element or species and a corresponding water quality standard or criterion in order to gain insight into the relative quality of the FBC waste leachates.

I.2 Chemical Mechanisms During Leaching and Attenuation/Mobilization

I.2.1 Overview of Chemical Mechanisms

The major emphasis in the chemistry discussions in other appendices was on the concentrations of elements leached from FBC wastes and attenuated by (or mobilized from) the disposal media. But the form of speciation was not

investigated. The purpose of this section is to review the types of chemical reactions that may occur among major and trace constituents when FBC wastes are leached and when FBC waste leachate is attenuated. In addition, chemical mechanisms are qualitatively identified where possible.

In actual field disposal, the FBC wastes may be leached by rainfall, surface runoff, or groundwater. The chemical composition of the leaching solution will result in differences in leaching mechanisms. If the FBC wastes are buried, the soil chemistry and bacteriological transformations may also be active in mobilization of trace elements.

Release to and uptake from solution of dissolved constituents by solids in contact with an eluant may involve any of several mechanisms. These include precipitation/dissolution, adsorption/desorption, ion exchange, complexation and chelation, oxidation/reduction, and biological activity. Each of these mechanisms is discussed below and is advanced, where appropriate, as a possible explanation of observed concentration behaviors in a subsequent section. When time dependency is a factor, diffusion and dispersion are also involved in the observed behavior.

I.2.1.1 Dissolution and Precipitation

Dissolution and precipitation reactions are very significant in the reaction of water with FBC solid wastes. Derivation of chemical equilibrium relationships can aid in prediction of which reactions may occur. However, chemical equilibrium is not always achieved due to the limiting kinetics of the reactions.

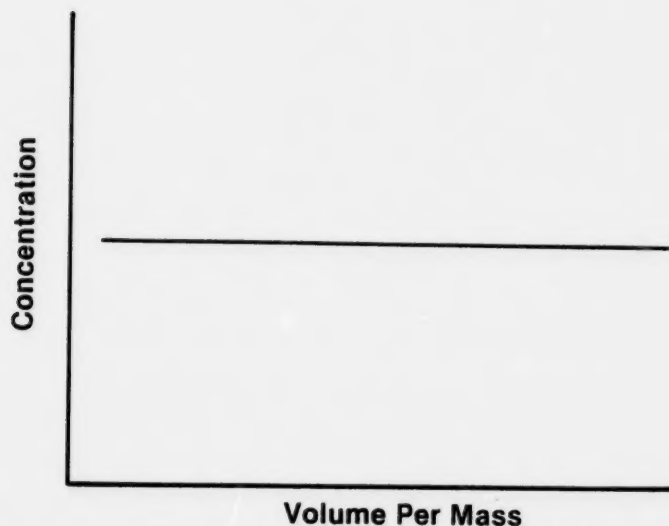
The solubility of oxides, hydroxides, and carbonates are dependent upon the concentration of their respective ligands. For this situation, the favoring of one phase over another is pH-dependent and a function of total inorganic carbon and atmospheric (closed or open) conditions. Precipitation/dissolution reactions have an additional complication if the affinity for other ligands (SO_4^{-2} , S^{-2} , PO_4^{-3} , CN^{-2} , etc.) competes with the formation of metal oxides, hydroxides, or carbonates.

Considerable thermodynamic data exist on the solubilities of mineral phases and the equilibrium distribution of aqueous species. These data apply to specifically defined solid phases (generally for crystalline solids, although values have also been generated for metastable, amorphous solids). Properly defined, complex systems can be described mathematically by solution of simultaneous equations. Numerous computer models are available for such solutions, but this type of analysis was performed in this investigation only on a limited basis (see Section I.4).

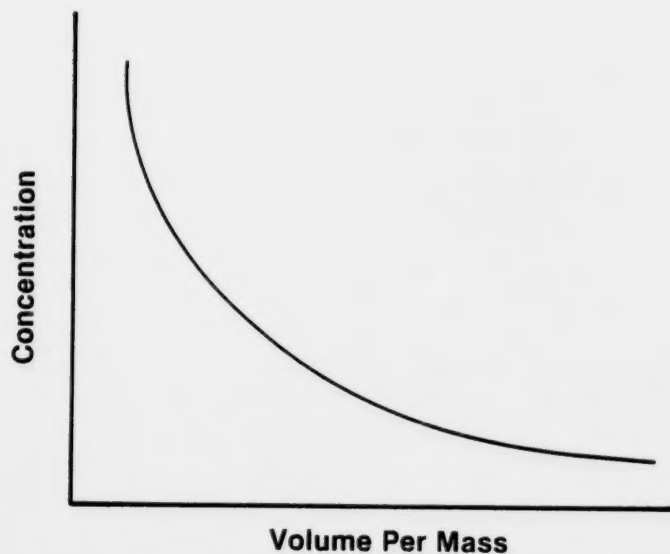
If a dissolution/precipitation reaction could occur in the batch leaching system where the species of interest are involved in only one reaction of congruent dissolution, only the ionic strength or temperature changes would alter the mass solubility of the solid phase. For such a simple system, repeated extraction of the solid phase would yield essentially a constant equilibrium concentration until the last repetition yielded complete dissolution of the solid phase (Figure I-1a). An idealized version of a typical leaching curve is shown in Figure I-1b. For dissolution reaction such a curve results when the dissolution of a species is limited by kinetic factors. Initially, the leach rate of the solid is rapid as hydronium or hydrogen ions in the eluant exchange with the species on the surface of the solid particles. If the solid dissolves incongruently (i.e., the bulk of the solid dissolves at a slower rate than the species of interest), then a leached layer forms on the solid particles. Leaching of the species of interest is then limited by its ability to diffuse through the leached layer of the solid particle and eventually dissolve at the particle surface.

I.2.1.2 Adsorption/Desorption and Ion Exchange

Adsorption/desorption and ion exchange are other major mechanisms which may be active in the leaching of FBC solid wastes. These reactions are particular interest in reactions of FBC waste leachates with disposal media. Clay minerals and soil colloids are generally negatively charged due to adsorption of excess anions or an imbalance in the atomic structure of crystal lattices. Therefore, metal cations tend to sorb onto soils. Cation



- a. Simplistic view of repeated extraction where ions are involved in congruent dissolution where system is at equilibrium.



- b. Simplistic view of dissolution reaction in repeated batch leaching where species availability is limited.

NOTE: Leachate Concentration is Plotted as a Function of the Leachate Volume-to-Waste Mass Ratio (VPM).

Figure I-1. Hypothetical Concentration Behavior with Increasing Leaching in an Idealized System Involving Only One Chemical Reaction.

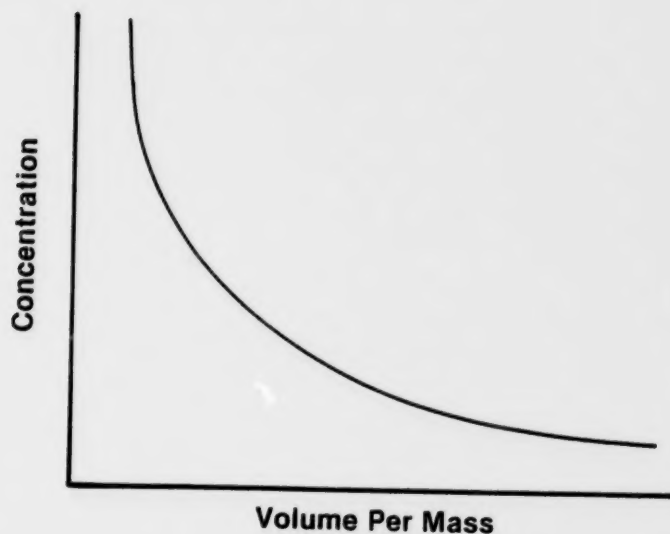
adsorption is generally affected by the type of cation and its concentration, the nature of the associated anions, and the nature of the colloid particle. According to the Schulze-Hardy rule, the higher the valence of the cation, the greater the tendency to adsorb on clays. With ions of the same valence, those which are least hydrated are the most difficult to remove from a clay surface.

Ion exchange reactions are affected by the chemical, physical, and biological properties of soil systems. The presence of iron and manganese oxides or organic matter is particularly significant. The presence of acidic (humic) oxidation products in soils may provide specific sorption sites for metal ions. Figure I-2 illustrates typical curve shapes for adsorption/desorption and ion exchange type mechanisms. Figure I-2a represents adsorption when a contaminated leachate is successively exposed to fresh solid sorbing material. Similarly, it depicts the concentration change that would occur in a waste leachate as it percolates through a sorbent material. Desorption behavior depicted in Figure I-2b might occur when an uncontaminated water is repeatedly exposed to either waste or contaminated soil where desorption of the species occurs with a constant distribution coefficient (K_D).

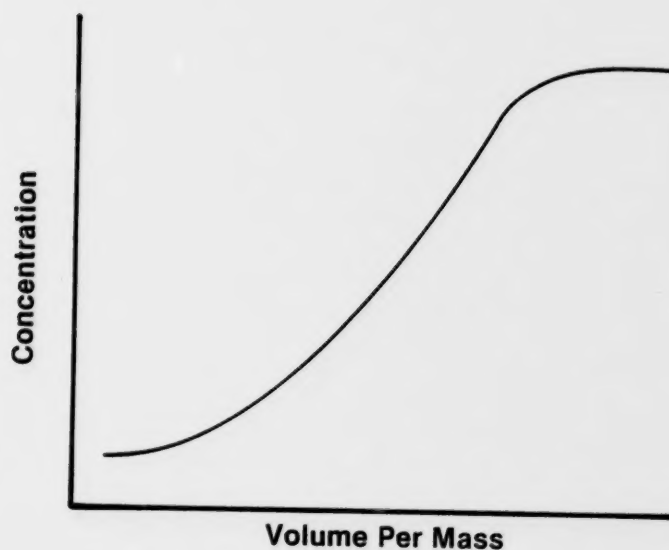
I.2.1.3 Complexation and Chelation

Complexation is the formation of compounds in aqueous solution by the coordinate covalent bond between a metal ion and an appropriate ligand group. As metal cations combine with anion ligands, the species become complexed even though they are not precipitated. Chelation involves attachment of more than one ligand to a metal base.

Hydrolysis of metal ions results in a series of proton transfers, and polymeric hydrolysis species can result in the process. Because the hydroxides or hydrous oxides of many trivalent and tetravalent metal ions are stable species in natural waters, the hydrolysis reaction is especially important. As a result, many bivalent metals will have CO_3^{2-} , S^{2-} , and PO_4^{3-} competing with OH^- as a coordination ligand.



a. Adsorption behavior.



b. Desorption behavior.

Figure I-2. Simple Curve Shape for Successive Batch Leaching When Adsorption-Desorption and Ion Exchange Type Mechanisms Are Operative.

Metallic ions from FBC wastes may be greatly affected by the action of organic chelating agents. Organic chelation has been cited for forming metal complexes in natural waters in which the metal ion concentrations exceed nominal expected levels based upon the solubility product constant. Well known organic chelating agents include amino acids, fatty acids, organic phosphorous compounds, and aromatic compounds containing -OH and -COOH functional groups. In past studies of organic chelating agents in other coal wastes, complexation was observed with ferrous iron and prevented precipitation or adsorption.

Complexation behavior, where the formation of a stable aqueous complex enhances a metals solubility, would exhibit the same general behaviors of the dissolution reactions presented in Figure I-1.

I.2.1.4 Oxidation/Reduction

Oxidation/reduction (redox) reactions in water may have a pronounced effect on solution composition. These reactions are generally slow and often require the presence of a catalyst. Redox reactions are also environmentally dependent (i.e., on or within a solid surface). Many of the major elements within FBC waste (e.g., C, N, O, S, Fe, and Mn) undergoing redox processes in natural environments will serve as controlling factors for the solubilities of metals. If a metal behavior is coupled to redox activity, its solubility will be affected by redox changes. Sulfide solubility control of metal ion concentration is an example of a mechanism that would be closely dependent upon redox conditions.

Redox and acid-base reactions can work synergistically in the release of metal ions from coal ash waste. For example, pyritic iron in coal can be oxidized in the surficial environment to ferric iron and sulfuric acid. This process leaves the crystal matrix susceptible to acid attack and dissolution. Oxidation of Fe^{+2} to Fe^{+3} can be accompanied by the departure of the cation from the crystal lattice leaving a defective crystal structure equally susceptible to acid attack and dissolution.

I.2.1.5 Biological Activity

Biological activity has been determined to indirectly both enhance and inhibit trace element reactions in natural waters. An example of biological activity is microbial methylation of elemental mercury. Microbial breakdown of organic matter to humic acid can result in inorganic-organic complexation with trace elements from the coal wastes.

In soils, microbial activity is often responsible for the breakdown of organic matter to produce inorganic acids (H_2CO_3 , HNO_3 , H_2SO_4 , H_3PO_4) and organic acids (humic, fulvic, crecic, apocienic, oxalic, and lichenic acids). These acids activate trace elements from the minerals in the soils. The same type of reaction could occur with FBC wastes. The same curve shape resulting from dissolution will be observed where biological interaction enhances mobilization of trace elements.

I.2.2 Relating Sequential Batch Extractions to Continuous Column Leachings

Chromatographic theory treats continuous elution of a solid by a fluid as a series of equilibrium steps when there is a distribution of a substance between the two phases. For sorption behavior, the analogy is direct. For solubility, however, partitioning is not involved. Instead, a constant concentration results until the solid is completely dissolved, and normalizing to a volume-per-mass (VPM) basis is no advantage. But neither is it a hindrance because if true equilibrium exists, the volume-concentration relationship will be a horizontal line and the cumulative mass versus volume relationship should be a straight line with a slope determined by the solubility product of the controlling solid phase. These relationships hold as long as the solid phase is present. Thus, a conceptual link is established between laboratory batch equilibration results and results from leaching columns even though a column experiences intermittent rather than continuous flow.

Figure I-3 illustrates the ideal correlation between batch and column leaching for desorption behavior. A desorption mechanism is implied but the rapid decline of concentration to a more or less constant value could also fit a solubility-controlled system where the initially high concentrations could be related to a combination of the common ion effect (relative to the counter ion species) or formation of a secondary product layer on the surfaces of the solid particles thus inhibiting dissolution.

For the linkage between batch and column leachings to be direct from a theoretical perspective, the effective distribution coefficient (whether a sorption, ion exchange or solubility constant) must be the same or must vary in the same manner with change in VPM.

According to Houle and Long and others (Reference I-1), the operative or conditional distribution coefficient (and solubility product) for mass concentration is not only temperature-dependent but also depends upon pH, ionic strength, presence of competing ions, current surface energy of the solid(s), effective surface area of the solid(s), and previous history of the solid(s). Kinetic factors may also be involved, especially when aging of original solids and/or secondary solids (produced by solution changes) from an amorphous to a crystalline structure can occur. Redox conditions cannot be ignored either.

Other differences between batch and column studies relate to differences in saturation conditions. Column studies typically relate to field conditions of vadose or unsaturated conditions. For this reason, and because of the potential differences in surface perturbations (abrasion in batch processes via mixing), kinetic limitations may play a major role in one system and not in the other. Differences in solid solution formation with resultant influences on solubility and sorption-ion exchange behavior between batch and column may be significant.

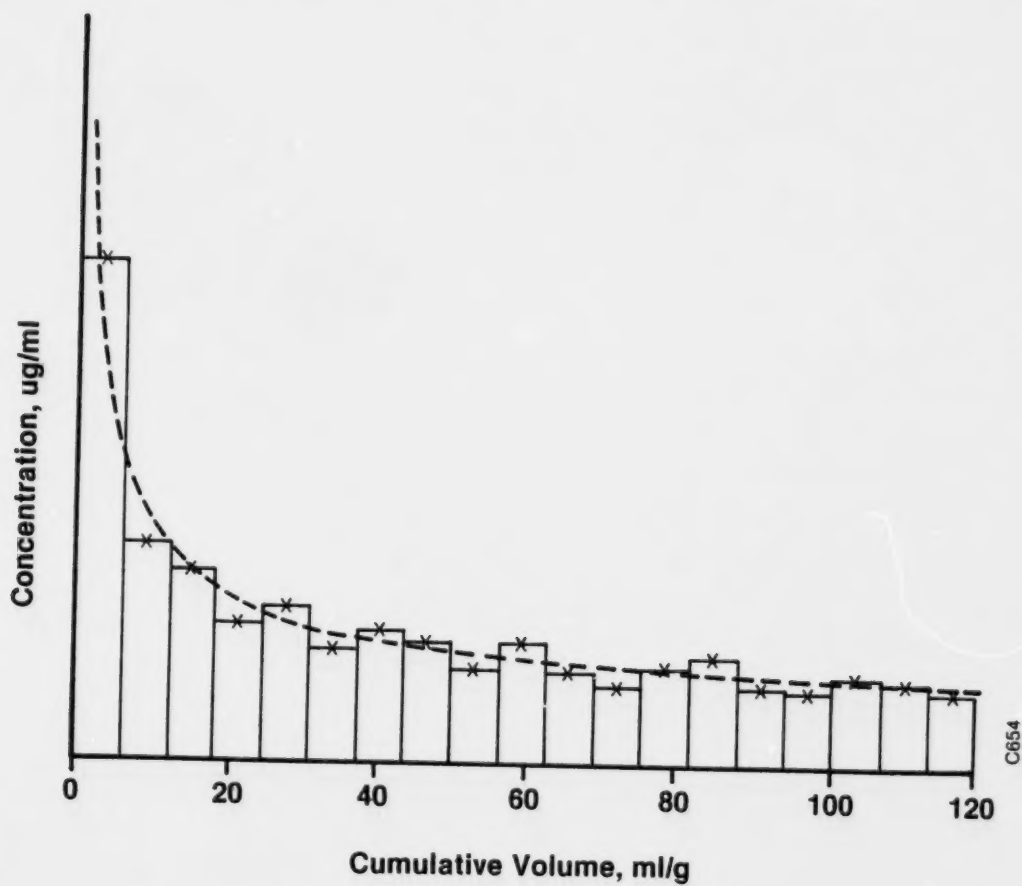


Figure I-3. Correlation of Batch with Continuously Leached Columns.
(Reference I-1.)

I.2.3 Categorization of Concentration Behavior

Several stipulations were required to make the extraction data collected under the different extraction conditions of the batch equilibration protocol comparable, the field column, and the lab column systems. For leaching behavior, concentration trends were assessed as a function of the cumulative volume of eluant per mass of waste leached (VPM). Similarly, for attenuation/mobilization behavior concentration trends (Section I.6) were assessed as a function of the cumulative volume of eluant per mass of disposal medium. This normalization of concentration data allowed observation of these data in terms of the vastly different liquid-to-solid ratios for the different extraction systems. The ranges of VPM ratios for leaching and attenuation/mobilization for the lab and field studies are given in Table I-1.

TABLE I-1. VOLUME-PER-MASS RANGES FOR LEACHING AND ATTENUATION/
MOBILIZATION EXPERIMENTS

Exponential Component	Leaching Volume per Mass (mL/g)	Attenuation/ Mobilization Volume per Mass (mL/g)
Laboratory Protocol (Sequential Batch)	0-100	0-70
Laboratory Leaching Columns	0-3	0-1.2
Field Cells	0-1.8	0-1.2

For the purposes of integrating the information generated by laboratory sequential batch extraction, Steps 1, 2, 3, and their repetitions were grouped to illustrate leaching behavior of the waste. Steps 4, 5, 6 and their repetitions were used to evaluate the attenuation/mobilization data. (Step 1 provides concentration data for VPM = 10, Step 2 repetitions provide

concentration data for $VPM > 10$, and Step 3 concentration data are plotted in the region where $VPM < 10$).

In the survey of concentration trends given below, curves from the lab protocol having a certain shape or trend at a given VPM were considered equivalent to a field cell curve having a similar shape even though the VPM of the field cell curve was much different. Also, the analysis did not fully address the slopes of curves; only general curve shapes as illustrated in the examples given the following sections are considered for behavior trend categorization.

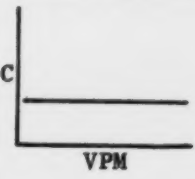
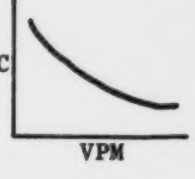
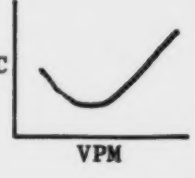
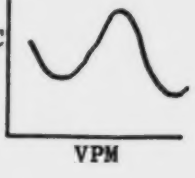
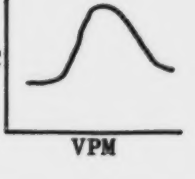
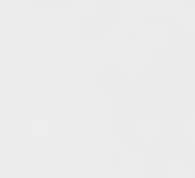
I.3 Survey of Concentration Trends During Leaching

Concentration behaviors were summarized for groups of elements having similar concentration trends to aid in chemical interpretation. This interpretive approach was designed to: (1) determine types of major behavior trends for each study component; (2) identify elements having a singular behavioral trend; and (3) provide a means of cross-comparison for elemental behavior in sequential batch extraction (laboratory protocol), extraction in laboratory leaching columns, and field cell operation.

I.3.1 Behavior Trends from the Batch Equilibration Protocol

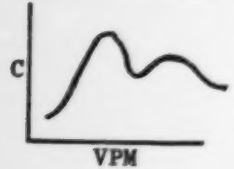
The behavior trends observed during Steps 1, 2, and 3 of the protocol were categorized, and the principal behavior trends observed are shown in Table I-2. The majority of species fell into the category of constant concentration with increasing VPM (Trend A). This behavior represents primarily trace elements for which concentrations were always low; however, it also represents the behavior of some higher-concentration elements which leach at a constant rate with increasing VPM. A constant release could be indicative of several simple mechanisms, such as equilibrium-controlled dissolution/precipitation, adsorption/desorption, or chelation/complexation reactions.

TABLE I-2. BEHAVIOR TRENDS OBSERVED IN PLOTS OF CONCENTRATION VERSUS CUMULATIVE VPM FOR LABORATORY PROTOCOL LEACHING

Curve Shape	Possible Mechanism	Element/Species ¹	
	A. Constant release, or no release due to low concentration of species	As(1,3)	Ni(1)
		Be(1)	Pb(1,3)
	B. Availability: initial rapid release of constituents ²	Cd(1)	Se(1,3)
		Co(1)	Ti(1)
	C. Delayed release, possibly solubility-controlled, pH-controlled, complexation controlled or due to physical or chemical changes in the solid surface.	Cu(1) ²	TIC (1,3)
		K(1,3)	TOC(1)
	D. Complex behavior; solubility-controlled release, physical/chemical changes in solid surface, formation of different solid phases, or others.	Kg(1)	U(1,3)
		Mo(1)	V(1)
	E. Complex behavior; solubility or pH-controlled delayed release, physical/chemical changes in solid surface, formation of different solid phases, or others.	Mn(1)	
		B(1)	Na(3)
		Ba(1)	pH(1)
		Cl(1)	SO ₄ (3)
		Cr(1,3)	Sp. Cond.(3)
		Li(3)	Sr(1)
		Mo(3)	TDS(3)
		Ag(3)	Fe(3)
		Al(1,3)	Mn(3)
		B(3)	Ni(1,3)
		Be(3)	Si(1,3)
		Cd(3)	Ti(3)
		Co(3)	V(3)
		Cu(3)	V(3)
		Ba(3)	Na(1)
		Ca(1)	Zn(1)
		Fe(1)	SO ₄ (1)
		Li(1)	TOC(3)

(Continued)

TABLE I-2. (Continued)

Curve Shape	Possible Mechanism	Element/Species ¹
	F. Complex behavior; possibly release from two species delayed by solution factors e.g., pH, ionic strength, complexation with other species.	Ca(3) pH(3)

¹Numbers following species in parentheses indicates waste number. Waste (1) is Exxon PFBC waste, and waste (3) is Alliance AFBC waste.

Two other behavior trends in laboratory leaching were shown by a number of species. In Trend B, the curve exhibits linear to exponential decreases, indicating availability-limited elements which appear to leach initially from the waste rather rapidly. The second trend (Trend C) represents a more complicated behavior. The curve shape is defined by an initial gradual decrease in concentration followed by a final increasing trend. This behavior is characteristic for elements which may initially be unavailable for leaching for a variety of reasons (pH effect, complexation with other species, etc.). As the leachate composition changed, the conditions for leaching were favored. Some caution must be taken in the assessment of elements falling under this category since some of these trace metals are in concentration ranges for which artificial trends may be observed due to analytical variability as opposed to an actual trend in leaching behavior.

Other behavioral trends were less common for the elements surveyed. The remaining three trends have in common at some point the attainment of a maximum followed by a decline in concentration. Differences in the final three trends are in the approach to the maximum and decline from it. The three variations observed may have exhibited similar curve shapes if the studies were carried out longer (i.e., more repetitions). They may indicate solubility-limited behavior of the species or solid diffusion-controlled reactions. The variable partitioning behavior followed by release indicates that the release is not a simple matter of dissolving available species. The behavior trend for calcium (doublet) indicates that there may be two different calcium species present which leach from the waste at a different rate.

I.3.2 Behavior Trends in Laboratory Leaching Columns

The concentration trends for leachates from the three lab leaching columns that contained no lower layer of disposal media were analyzed. These column arrangements are similar to scaled-down field cells and included pulverized Alliance AFBC waste with an overlayer of sandstone and pulverized and unground Exxon PFBC waste with an upper layer of shale. Figure I-4 shows the three columns included here (LC-1, LC-2, and LC-3) and

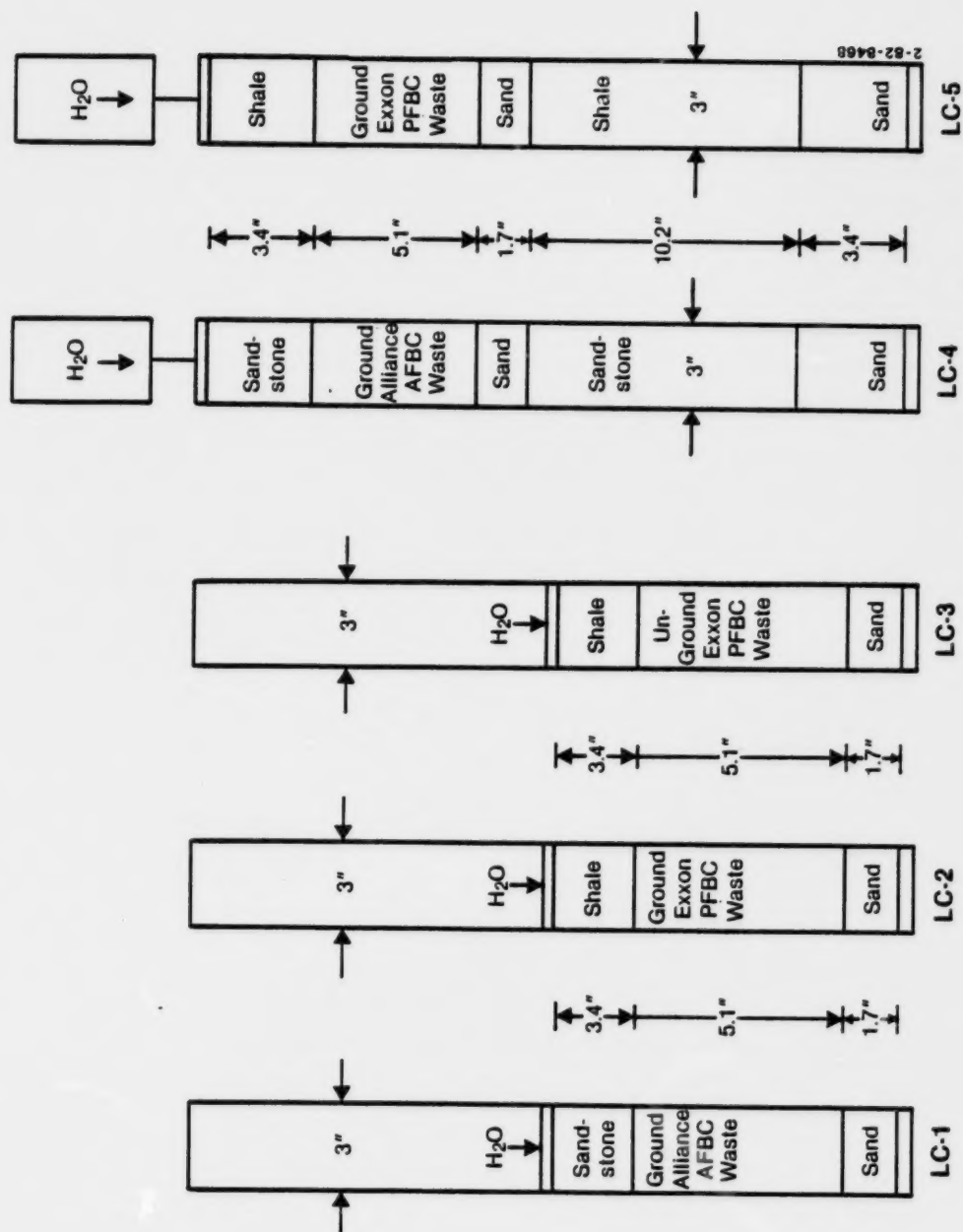


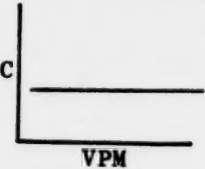
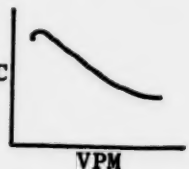
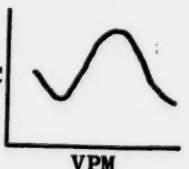
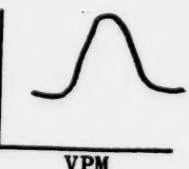
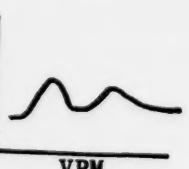
Figure I-4. Schematic Configuration of the Laboratory Leaching Columns.

the two columns with a lower layer of disposal medium also. The five types of behavior observed in the column leaching experiments are shown in Table I-3. No unique curve shapes were observed for the columns. All curve shapes generated in column leaching also occurred for different sets of elements during batch equilibration leaching; however, because of differences in the chemical systems in the batch leaching and leaching column studies, different mechanisms are probably responsible for producing equivalent curve shapes. Also, in the column leaching there is the possibility of residual release from the disposal media overlayer and interactions between the waste and the overlayer during leaching.

In many previous column leaching experiments conducted on conventional utility wastes, elements exhibited leaching behaviors similar to trends A and B. These previous studies were operated under saturated continuous flow, whereas the columns in this work involved unsaturated, intermittent flow. This difference in flow could be a major factor in the complex behaviors noted in the laboratory column leachings conducted on FBC waste.

Constantly low concentrations with increasing VPM were observed in some cases, and availability-release of highly soluble species was observed for others (Trends A and B). The majority of species, however, fell into three trend categories characterized by curves which pass through a maximum value at some intermediate VPM. One of these trends is distinct in that the initial concentration is moderately high and goes through a minimum concentration before a maximum concentration is attained, followed by another decrease (Trend C). This behavior may indicate a sorption/desorption cycle or dual contributions from the waste then the disposal medium in the form of different speciation of the element. The other chromatographic behaviors are characterized by initially low concentration values. Trend D behavior may be solubility-limited with a delayed release due to factors controlling solution chemistry. The final behavior type (Trend E) consists of a diffuse doublet indicative of sorption/desorption cycling or possibly contributions from two species containing the element, or separation in time of the release from the waste and the disposal medium.

TABLE I-3. BEHAVIOR TRENDS OBSERVED IN PLOTS OF CONCENTRATION VERSUS CUMULATIVE VPM FOR LABORATORY LEACHING COLUMNS

Curve Shape	Possible Mechanism	Element/Species ¹	
	A. Release due to low concentration of species	Sr(2,3)	TiC(1-3)
	B. Availability-release of species	Cl(1,3) Fe(2,3)	Mo(2,3) Sr(1)
	C. Complex behavior, possibly sorption-desorption cycles. Could be elemental contributions from two species or leachate from waste followed by leachate delayed effect due to species leached from the overburden	Al(1-3) B(1-3) Ca(1-3)	Cd(1-3) Cr(1-3) Ni(1-3)
	D. Solubility-limited; delayed release due to changes in solution chemistry with cumulative leaching	Ba (3) Co(1-3) Cu(1) F(1) K(2,3) Li(2,3)	Mg(3) Mn(3) Na(2) SO ₄ (1-3) Ti(1-3)
	E. Complex behavior; possibly sorption desorption, solubility-limited, or others	Ba(1-3) Cu(2,3) Fe(1-3) K(1-3) Mo(1) Na(1,3) pH(1-3)	Si(1-3) Sp. Cond. (1,3) Ti(1-3) V(1-3) Zn(1-3)

¹Numbers in parentheses after species indicates column number with contents as follows:

- 1: Column LC-1 = sandstone over ground Alliance AFBC waste
- 2: Column LC-2 = shale over ground Exxon PFBC waste
- 3: Column LC-3 = shale over unground Exxon PFBC waste.

I.3.3 Behavior Trends in Field Cells

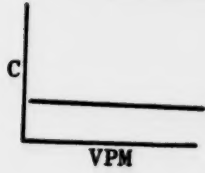
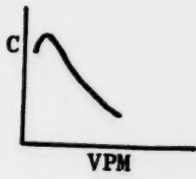
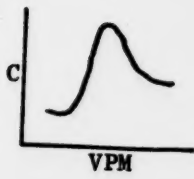
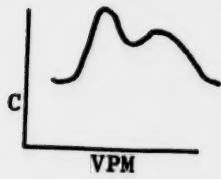
The curve shape trends observed in field leaching data are summarized in Table I-4. More species exhibited low constant release and high constant release (Trend A) than any other trend. Other mechanisms observed were availability-controlled release of soluble constituents in the waste (Trend B) solubility-controlled release producing delayed maximum concentrations (Trend C), and two complex behavior types.

I.4 Evaluation by Chemical Equilibrium Modeling of Solubility Control in Leaching

A Radian equilibrium computer model was used to calculate the relative saturation of calcium and magnesium with respect to various solid phases. Analytical or mass concentrations from solution analyses were used as input to the model. Ionic strength was evaluated, and the relative saturation values were generated from ion activity relationships which also include consideration of inorganic ion complexes and ion pairs.

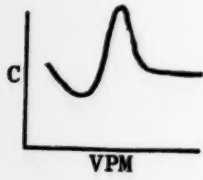
Table I-5 contains results from the Step 1 extractions of each of the three FBC wastes. Of interest is the consistent near-saturation (or slight oversaturation) with respect to gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). This is consistent with the presence of gypsum in the X-ray diffraction data (Appendix C). The results indicate that for the batch extraction system, a simple dissolution model might be adequate for calcium sulfate. The Exxon PFBC waste and the Alliance and Georgetown AFBC wastes show a consistent difference relative to calcium hydroxide saturation; the former is not even near saturation while both AFBC systems show oversaturation. The extreme oversaturation with respect to magnesium hydroxide is likely a result of the high pH and extreme insolubility of magnesium hydroxide at these pH values.

TABLE I-4. BEHAVIOR TRENDS OBSERVED IN PLOTS OF CONCENTRATION VERSUS CUMULATIVE VPM FOR LEACHATE GENERATION IN FIELD CELLS (UPPER SAMPLING POINT)

Curve Shape	Possible Mechanism	Element/Species	
	A. High constant concentrations indicate solubility-limited behavior; low constant concentrations indicate low availability of leachable species	B(5,13-17) Mg(13-16) Be(5,15,16) Mn(4,6, Ca(1,2,6) 13-17) Cd(16, low) Na(13-17) Cl(1,4,5,6) pH(1,2,4) Fe(3,5,17) SO ₄ (14-17) Hg(1-7, 12-17, low) Sr(1-6, low) Li(4) TDS(15,16) Zn(13,16)	
	B. Availability-controlled release of constituents	B(1-4,6) pH(6,13, Cl(2,13-17) 15-17) Co(15-17) SO ₄ (1-6) Cr(5) Sp. Cond. Cu(13-17) (all) F(1,3,4) TDS(1-6,13, Fe(15) 14,17) Li(1-3,5,6) Ve(13) Na(1-6) Zn(14,15)	
	C. Possibly solubility-controlled release or delayed release due to solution chemistry	Be(2,3,4, 14) K(1-6,16,17) Ca(13-17,3, 4,5) Li(13,16,17) Cd(13,15) Mg(1-6,17) Co(1-6,13, 14) Mn(1-3,5) Fe(1,2,4, 6,13) pH(14) Si(13-17) SO ₄ (13) Zn(1,17)	
	D. Complex behavior; possibly release from two species; delayed release possibly chemistry	Be(1,16) Ti(1-6,17) K(13-15) V(all) pH(3) Zn(2-6)	

(Continued)

TABLE I-4. (Continued)

Curve Shape	Possible Mechanism	Element/Species	
	E. Complex behavior; possibly solubility-limited or sorption-desorption cycling	Cd(1-6, 14,17)	Mo(all)
		Cr(1-3, 13-17)	Ni(13-17)
Other behaviors: multiple peaks	F. Complex	Li(14,15)	pH(S)
		Mg(1-6,17)	Si(1-6)
			Sr(13-17)
			Ti(13-16)
		Al(all)	F(13-17,2)
		B(all)	Fe(17)
		Cr(4,6)	Ni(1-6)
		Cu(1-6)	Si(13)

¹Numbers in parentheses indicate field cell number for which species behavior was observed. These field cells contained the following:

- Cell 1 - Exxon PFBC Waste and Shale
- Cell 2 - Exxon PFBC Waste and Shale
- Cell 3 - Exxon PFBC Waste and Till
- Cell 4 - Exxon PFBC Waste and Limestone
- Cell 5 - Exxon PFBC Waste and Alluvium
- Cell 6 - Exxon PFBC Waste and Sandstone
- Cell 13 - Alliance AFBC Waste and Interburden
- Cell 14 - Alliance AFBC Waste and Alluvium
- Cell 15 - Alliance AFBC Waste and Alluvium
- Cell 16 - Alliance AFBC Waste and Limestone
- Cell 17 - Alliance AFBC Waste and Shale

TABLE I-5. PERCENT SATURATION OF PROTOCOL STEP 1 LEACHATES WITH
RESPECT TO CALCIUM AND MAGNESIUM COMPOUNDS

Sample	pH	Ionic Strength	Ca(OH)_2 Percent Saturation	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Percent Saturation	Mg(OH)_2 Percent Saturation
Exxon PFBC Waste Leachates					
L 170100A	11.8	0.071	6.5	119	325
L 170100B	11.9	0.086	12.3	129	2105
L 170100C	11.5	0.085	2.0	134	614
L 170100D	11.8	0.084	7.7	128	1256
L 170100E	11.5	0.095	2.3	135	589
Alliance AFBC Waste Leachates					
L 170300A	12.5	0.081	133	88.5	522
L 170300B	12.5	0.086	142	93.0	1270
L 170300C	12.5	0.085	143	92.3	2039
L 170300D	12.5	0.088	150	92.6	1282
L 170300E	12.5	0.088	150	93.4	2067
Georgetown AFBC Waste Leachates					
L 170400A	12.5	0.092	149	121	426
L 170400B	12.5	0.094	147	131	4721
L 170400C	12.5	0.089	141	115	2791
L 170400D	12.5	0.089	135	101	3806

The laboratory batch extraction values used in the computer model presumed low carbonate content. The only waste for which inorganic carbon data were obtained is the the Georgetown AFBC waste. The carbonate concentration was roughly 29 mg/L (based on 5.7 mg/L of inorganic carbon). Calcium carbonate was detected in x-ray diffraction of leached Alliance AFBC waste after leaching, but was absent in the Exxon PFBC leached waste.

Two indirect estimations were used to approximate the carbonate content of leachates from the Exxon PFBC and Alliance AFBC wastes. The first procedure was to conduct a solution charge balance by computing the total milliequivalents of positive and negative charged species in the leachate solution and examining the difference:

$$\text{Ion content (meq/L)} = \frac{n_i C_i}{M_i}$$

n_i = ion charge

C_i = ion concentration, mg/L

M_i = ion atomic/molecular weight

Table I-6 contains a listing of the cation and anion species presumed to be in the leachate solution at the high pH conditions observed. The resultant computations are presented in Table I-7 for each of the single (i.e., non-composite) replications of Step 1 for the three FBC wastes.

TABLE I-6. MAJOR IONS PRESUMED TO BE PRESENT IN THE WASTE LEACHATES

Ion	Charge	At/Mol Wgt	Ion	Charge	At/Mol Wgt*
Ba	+2	137	AlO ₂	-1	27
Ca	+2	40	BO ₂	-3	10.8
K	+1	39.1	Cl	-1	35.5
Li	+1	7	Co(OH) ₂	-1	58.9
Mg	+2	24.3	CO ₂	-2	60
Na	+1	23	CrO ₄	-2	52
Sr	+2	87.6	Cu(OH) ₂	-1	63.5
			F	-1	19
			Fe(OH) ₄	-1	56
			MoO ₄	-2	96
			Ni(OH) ₂	-1	58.7
			OH	-1	17
			SiO ₂ (OH) ₂	-2	28.1
			SO ₄	-2	96
			Zn(OH) ₂	-1	65.4

*Weight of species as analyzed not necessarily as the ion presented. Data base contains concentrations primarily as elemental analysis.

Included in the computations are activity corrections for the hydroxide concentration (since electrometric pH measurements more closely determine activity) and consideration of ion pair formation with hydroxide.

For the Exxon PFBC waste, considerable negative charge is still unaccounted for which would translate into an average carbonate concentration of 1328 mg/L or an average inorganic carbon concentration of 266 mg/L. Much

TABLE I-7. REVISED CHARGE BALANCES FOR STEP 1 EXTRACTIONS AND APPARENT CARBONATE CONTENT BASED THEREON

	Ezion PFBC				Alliance AFBC				Georgetown AFBC			
	Cations (meq/L)	Anions (meq/L)	Δ meq/L	Apparent CO_3^{2-} , (mg/L)	Cations (meq/L)	Anions (meq/L)	Δ meq/L	Apparent CO_3^{2-} , (mg/L)	Cations (meq/L)	Anions (meq/L)	Δ meq/L	Apparent CO_3^{2-} , (mg/L)
A	68.38	44.38	24	720	69.43	68.56	0.87	26.1	81.06	76.00	5.06	152
B	84.28	42.25	42.03	1261	75.03	70.04	4.99	150	81.28	78.92	2.36	71
C	84.56	34.28	50.28	1509	74.88	69.93	4.95	149	76.34	74.98	1.36	40.8
D	82.55	38.80	43.75	1313	79.07	69.83	9.24	277	71.27	71.35	-0.08	0
E	95.97	34.76	61.21	1837	79.02	70.19	8.83	265	-	-	-	-
Mean	83.15	38.94	44.26	1328	75.49	69.71	5.78	173.4	77.49	75.31	2.18	65.40

lower values are seen for the two AFBC wastes. Calculated average values for carbonate were 173.4 and 65.4 mg/L respectively for the Alliance and Georgetown wastes. Corresponding values for inorganic carbon would be 34.7 and 13.1 mg/L. These values are reasonable and correspond moderately well to limited TIC data taken in other phases of the project. The high values obtained for the Exxon waste are not compatible with levels of calcium found in solution and probably reflect a positive systematic error in analysis of one of the major cation species or a negative systematic error in one of the anion species.

Clearly, the ionic strength and total dissolved solids content of the leachate solutions are dominated by calcium, sulfate and hydroxide ions. Similarly, the conductance measurements also reflect this dominance, with the hydroxide concentration being most significant. Hydroxide ion has a disproportionately high contribution to total conductance relative to all other ions except the hydrogen ion. Therefore, total dissolved solids and conductance measurements are likely to be good predictors only for calcium, sulfate, and hydroxide. Small variations in these values and the resulting fluctuations in total dissolved solids and conductance would likely be greater than the total contribution of most other species in the leachate solution.

Table I-8 compares the total dissolved solids values obtained on Step 1 leachates for the three FBC wastes with summation of the measured concentration of ion species plus the computer-adjusted hydroxide content. For each waste, the average value obtained by ion summation is less than the average value of total dissolved solids. The magnitude of the difference is of the same order as found by the charge balance comparison. That is, the difference is greatest for the Exxon waste, less for the Alliance waste and least for the Georgetown waste. The overall difference is greater in each case than for the charge balance accounting. This is not surprising because the ion summation does not account for waters of crystallization that may be contained in the total dissolved solids value.

TABLE I-8. COMPARISON OF TOTAL DISSOLVED SOLIDS VALUES WITH SUMMATION OF LEACHATE ION CONTENT

	Exxon PFBC			Alliance AFBC			Georgetown AFBC		
	TDS (mg/L)	ions* (mg/L)	Δ mg/L	TDS (mg/L)	ions (mg/L)	Δ mg/L	TDS (mg/L)	ions (mg/L)	Δ mg/L
A	2320	2853	-533	3940	3257	683	4100	3821	279
B	3770	3156	614	3880	3405	475	4050	3962	88
C	3870	3054	816	3870	3394	476	3950	3687	263
D	4220	3076	1144	3890	3465	425	3740	3428	312
E	4180	3240	940	3870	3475	395	-	-	-
Mean	3672	3081	591	3890	3399	491	3960	3724	236
	Excluding A								

*Potassium values not included; they could be significant, but they could not be included due to high detection limit (40 mg/L).

For the field cell and laboratory leaching column data, carbonate levels were included in computations of solubility saturation. The average values of chemical species in the leachates from the field cells (upper sampling point) and laboratory leaching columns (LC-1, LC-2, and LC-3) were used as input to the model. Data from operation after 60 days were used to allow assessment of potential solubility control over the long term. Table I-9 contains a summary of the modeling results for the laboratory columns, and Table I-10 contains the results for the field cells.

Four separate input values were used for the solution carbon dioxide (carbonate) content of the laboratory column leachates—10 mg/L, 200 mg/L, 1000 mg/L, and presumed equilibrium with the atmosphere (0.0003 atmosphere carbon dioxide partial pressure). Of these four levels, only 10 mg/L carbon dioxide yields reasonable results. For this value of carbonate content, each of the column leachates (average composition after 60 days leaching) would appear to be saturated (actually oversaturated) with respect to calcium carbonate and slightly undersaturated with respect to gypsum although

TABLE I-9. CHEMICAL MODELING RESULTS FOR LAB LEACHING COLUMNS

Column	pH	Ionic Strength	Assumed CO ₂ Concentration	Percent Saturation				
				Ca(OH) ₂	CaCO ₃	CaSO ₄ ·2H ₂ O	Mg(OH) ₂	MgCO ₃
LC-1: Alliance AFBC Waste								
	12.0	150	0.0003 atm	6×10^{-1}	5.00×10^4	3.3×10^{-4}	3.9×10^{-3}	7.4×10^{-6}
	12.0	0.062	10 mg/L	16.2	185	85.4	704	-
	12.0	0.053	200 mg/L	18	3.7×10^4	-	692	7.3×10^{-4}
	12.0	0.053	1000 mg/L	18	3.8×10^4	-	692	7.3×10^{-4}
LC-2: Exxon PFBC Waste								
	12.0	150	0.0003 atm	3.2×10^{-4}	2.6×10^4	2.8×10^{-4}	0.04	7.8×10^{-6}
	12.0	0.05	10 mg/L	6.8	138	70.7	1406	-
	12.0	0.050	200 mg/L	6.5	3.0×10^4	75.2	623	1.4×10^{-8}
	12.0	0.058	1000 mg/L	3.1	1.1×10^4	38.8	344	6.2×10^{-8}
LC-3: Exxon PFBC Waste								
	12.0	150	0.003 atm	2.8×10^{-4}	2.3×10^4	2.2×10^{-4}	8.2	1.1×10^{-8}
	12.0	0.051	10 mg/L	6.8	138	70.7	1406	-
	12.0	0.051	200 mg/L	5.7	2.6×10^4	62.0	1.2×10^4	0.28
	12.0	0.058	1000 mg/L	2.8	9.5×10^4	32.6	7.1×10^4	1.2

TABLE I-10. CHEMICAL MODELING RESULTS FOR FIELD CELLS

Cell	pH	Ionic Strength	CO ₂	Percent Saturation				
				Ca(OH) ₂	CaCO ₃	CaSO ₄ ·2H ₂ O	Mg(OH) ₂	MgCO ₃
Exxon PFBC Cells								
1	7.6	0.063 0.062	190 mg/L 0.0003 atm	9x10 ⁻⁸ 9.6x10 ⁻⁸	295 23.3	86.4 88.1	8.1x10 ⁻⁴ 8.3x10 ⁻⁴	0.013 1x10 ⁻⁴
2	7.6 7.6	0.083 0.082	158 mg/L 0.0003 atm	1.0x10 ⁻⁶ 1.1x10 ⁻⁶	259 25.4	112 113	1.4x10 ⁻³ 1.4x10 ⁻³	0.017 1.7x10 ⁻³
3	8.7 8.7	0.057 0.058	68 mg/L 0.0003 atm	1.5x10 ⁻⁶ 1.4x10 ⁻⁶	1216 3471	88.0 85.9	0.10 0.1	0.04 0.1
4	7.5 7.5	0.054 0.052	250 mg/L 0.003 atm	7.1x10 ⁻⁸ 7.4x10 ⁻⁸	352 17.7	81.1 83.3	2.8x10 ⁻⁴ 2.9x10 ⁻⁴	6.9x10 ⁻³ 3.5x10 ⁻⁴
5	8.0 8.0	0.65 0.064	205 mg/L 0.003 atm	5.8x10 ⁻⁸ 5.9x10 ⁻⁸	705 143	68.9 70.5	2.6x10 ⁻³ 2.6x10 ⁻³	0.016 3.2x10 ⁻³
6	7.5 7.5	0.059 0.058	230 mg/L 0.0003 atm	7.0x10 ⁻⁸ 7.2x10 ⁻⁸	316 17.4	85.1 87.2	8.9x10 ⁻⁴ 9.1x10 ⁻⁴	0.02 1.1x10 ⁻³
Alliance AFBC Cells								
13	7.7 7.7	0.046 0.045	147 mg/L 0.0003 atm	1.0x10 ⁻⁶ 1.0x10 ⁻⁶	191 25.3	41 42	3.7x10 ⁻³ 3.7x10 ⁻³	3.5x10 ⁻⁴ 8.6x10 ⁻⁴
14	8.7 8.7	0.044 0.044	150 mg/L 0.0003 atm	5.6x10 ⁻⁷ 5.6x10 ⁻⁷	1125 1341	27.9 27.7	1.3x10 ⁻³ 1.3x10 ⁻³	1.3x10 ⁻³ 1.6x10 ⁻³
15	7.7 7.7	0.062 0.061	150 mg/L 0.0003 atm	6.8x10 ⁻⁸ 6.9x10 ⁻⁸	147 16.7	41.9 42.6	7.3x10 ⁻³ 7.4x10 ⁻³	7.8x10 ⁻⁴ 9.0x10 ⁻⁴
16	7.6 7.6	0.046 0.045	198 mg/L 0.0007 atm	8.4x10 ⁻⁸ 8.6x10 ⁻⁸	165 20.8	44.2 45.4	9.0x10 ⁻⁴ 9.2x10 ⁻⁴	1.4x10 ⁻⁴ 1.1x10 ⁻⁴
17	7.6 7.6	0.046 0.045	195 mg/L 0.0003 atm	1.3x10 ⁻⁸ 1.3x10 ⁻⁸	360 31.0	53.5 54.9	2.4x10 ⁻³ 2.5x10 ⁻³	3.5x10 ⁻⁴ 3.0x10 ⁻⁴

for both species, these data probably are indicative of solubility control for calcium, carbonate, and sulfate. Magnesium hydroxide is greatly oversaturated, implying pH control of magnesium as stated above.

The field cell data of Table I-10 are presented for two carbon dioxide levels. One value presumed equilibrium with the atmosphere, and the other was developed from conversion of the mean total inorganic carbon value for the individual columns into equivalent carbonate concentration. Consequently, the conversion values (upper value) for each cell more likely represents the real relative saturation in the individual columns.

The strong implication of the table is that all field cells for both wastes are saturated with respect to calcium carbonate. The oversaturation values could be related to inaccuracies in assessing the carbonate value or a mismatch between actual system temperature and that used in the thermodynamic model data base. Calcium sulfate was near saturation in the Exxon PFBC field cell leachates (in most cases) but much lower values for the relative saturation with respect to gypsum were calculated for the Alliance AFBC field cell leachates.

These results support speculation that the formation of calcium carbonate on the waste surface ("armouring") was controlling the pH and sulfate concentrations in the field columns. While saturation with respect to calcium carbonate (and calcium sulfate) are also implied in the laboratory column data, the high pH values maintained in the lab columns points to some critical difference in the preparation and maintenance of these two systems (field and lab).

I.5 Comparison of Leachate Concentration Ranges for Leachate Generation in the Lab and Field Studies

In order to obtain an overall comparison of the results of the leachate generation phase of the major components of the lab and field investigation, plots were prepared for each analytical parameter showing the range of concentrations observed. Similar plots were not prepared for the attenuation

phase. Each plot consists of four major parts, one for the leaching results for each of the three FBC wastes and one for leaching of the disposal media. For the Exxon PFBC wastes, data are plotted for field cells 1 to 6, for laboratory protocol Steps 1, 2, and 3, and for laboratory leaching columns LC-2 and LC-3. For the Alliance AFBC wastes, plots are included for field cells 13 to 17, protocol Steps 1, 2, and 3, and lab leach column LC-1. Plots for the Georgetown AFBC waste are included for protocol Steps 1 and 2. The disposal media plots include data from field cells 7 and 12 (the field control cells), the lab control columns, and protocol Steps 1 and 2.

A log (base 10) scale was used to permit convenient representation of all the data on a single diagram. In the text discussion of the diagrams, approximate concentration values as estimated from the diagrams are used rather than the precise values used from the data base when the diagrams were prepared. For Step 1 of the protocol, which did not involve time series data or the sequential batch leaching equivalent, a range was not plotted. Instead, the mean and median values of the replicates are presented. For some of the parameters, varying detection limits appear because of different dilutions required to adjust concentrations of the major species so that they were within the range of the primary analytical instrument used (ICAPES). When the means and medians were determined, detection limit values were included in the computation with a value of zero.

For the field cell systems, two conventions were employed. First, the overall range was restricted to data corresponding to samples taken after at least 30 days of operation. Especially for the Exxon PFBC field cells, very early elution samples had extremely high concentration values for specific elements that were atypical of the long-term behavior. While these high concentrations are not to be summarily dismissed, their representation in the figures would represent an inappropriate bias.

Second, the field cell ranges for samples taken on 17 July, 17 August, and 17 September 1981 were plotted in bold face on the overall ranges. While the Exxon PFBC and Alliance AFBC cells had been in operation for different periods of time on those dates, comparison of leachates sampled then

provide a basis for direct comparison with common sampling times, common analysis times, and samples corresponding to warm climatological conditions, all of which provided a desired refinement of the data comparison. When data were not available for all three sampling dates or when identical values were obtained, a boldface dot was used.

A similar convention was adopted for the laboratory control column data except that the boldface representation applies to the last three samples taken from the respective columns.

The following sections present observations regarding the concentration ranges. The parameters are discussed in alphabetical order. Table I-11 shows the legend for the symbols and abbreviations used in the concentration range plots in subsequent figures.

I.5.1 Aluminum

The plots for the concentration ranges for aluminum are shown in Figure I-5. The mean concentration for protocol Step 1 leaching of the Exxon PFBC waste was 0.8 mg/L. Step 2 leaching resulted in a concentration range relatively close to the Step 1 value, but Step 3 leaching gave a range slightly lower than the Step 1 value (about 0.3 to 0.5 mg/L). The field cells containing PFBC waste yielded leachate with consistent aluminum concentrations ranging from detection limit values (<0.1 mg/L) to about 5 mg/L. During the latter part of field cell operation (17 July, 17 August, and 17 September 1981), the leachate had concentrations in the 0.2 to 2 mg/L range, which are quite comparable to the lab protocol results. The lab leaching columns with PFBC waste (both of which also had a layer of shale above the waste) also had consistent results, with concentrations ranging from detection limit values to 2 mg/L.

For the Alliance AFBC waste, the mean Step 1 concentration value was about 1 mg/L. Repetitions of both Step 2 and 3 yielded leachates with aluminum concentrations in the 0.1 to 2.0 mg/L range. All field cells containing Alliance waste had consistent aluminum concentration results, with

TABLE I-11. LEGEND FOR FIGURES I-5 TO I-30

- G.A. = Georgetown AFBC Waste
D = Detection Limit
× = Median
• = Mean
● = Identical Values for 17 July, 17 August, and 17 September 1981 Samples
• = Data Point for Batch Equilibration Protocol Leaching of Disposal Media

Heavy bar on field cells and lab control columns

- ┌ - Field cells - 17 July, 17 August, 17 September 1981 values
└ - Lab control columns - last three samples

Disposal Media Code

- Sh = Shale
I = Interburden
Ss = Sandstone
GT = Glacial Till
Al = Alluvium
Li = Limestone
-

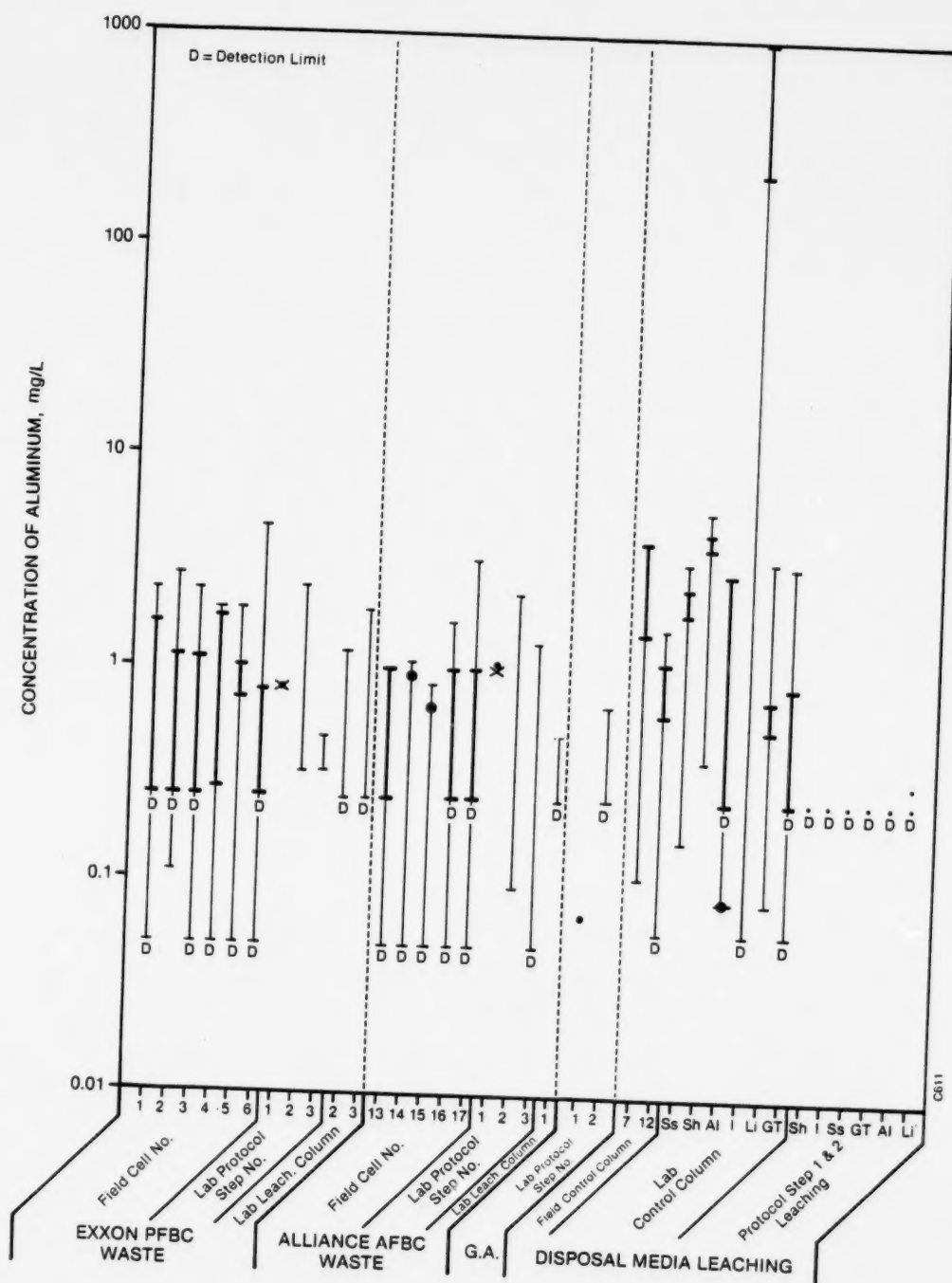


Figure I-5. Concentrations of Aluminum of Leachates Generated From FBC Wastes and Disposal Media.

concentration ranging from detection limit values (<0.1 mg/L) to 3 mg/L. Again, during the latter part of the period of operation, the field cells yielded leachates with concentrations that were quite comparable to but slightly below the lab protocol results. The results from the lab leaching column containing Alliance waste (which also had a layer of sandstone over the waste) were very similar to the protocol and field cell results.

Only protocol Steps 1 and 2 were performed on the Georgetown AFBC waste. The mean concentration of the Step 1 leachates was about 0.07 mg/L, although five of the six leachates included in the computation were at or below the detection limit value of 0.25 mg/L. The range for leachates derived from repetition of Step 2 was from the 0.25 mg/L detection limit to about 0.7 mg/L.

The three FBC wastes tested yielded leachate concentrations of aluminum that were relatively similar for all phases of the program. In general, the concentrations were relatively low (<5 mg/L), and the ranges of concentration were over about two orders of magnitude.

Batch (protocol Step 1) leaching of the disposal media resulted in aluminum concentrations at or below the detection limit. Leaching of the disposal media in field cells and control columns yielded concentrations that were quite similar for all media except interburden. The range of concentrations were generally the same as for the FBC wastes (detection limit values to about 6 mg/L). The exception to this generalization was the high concentration found for the interburden in the lab control column. This anomalous finding undoubtedly resulted from the low pH that existed in this column.

The ranges of aluminum concentrations in leachates from the FBC wastes were generally not significantly different from the concentrations in leachates from the disposal media. Batch leaching of the wastes resulted in higher concentrations than similar leaching of the disposal media, but lab and field column studies yielded the same concentration ranges for the

wastes and disposal media. All lab and field studies (except the lab control column containing interburden) yielded leachates with aluminum concentrations below 6 mg/L.

I.5.2 Barium

The results of the barium analyses for the lab and field leaching of the FBC wastes and the disposal media are shown in Figure I-6. Overall, the concentrations varied over a broad range from detection limit values (<0.001 mg/L) to slightly more than 1 mg/L. The upper limit of the concentration range was close to 1 mg/L for the majority of the study components.

For the Exxon PFBC waste, the mean Step 1 leachate concentration for barium was about 0.2 mg/L. The Step 2 repetitions resulted in a range lower than the Step 1 value (0.04 to about 0.1 mg/L), whereas Step 3 repetitions resulted in a higher range of values, around 0.3 mg/L. Three of the field cells showed concentration ranges from 0.02 to about 1 mg/L. The other three field cells had a broader range from <0.001 to 1 mg/L. The ranges for the three sample days selected from the latter period of the field cell operation were much narrower and were somewhat higher than the protocol Step 1 and 2 values; values were in the 2 to 7 mg/L range. The lab leaching columns had a concentration range comparable to the latter part of the field cell operation period.

The mean Step 1 leachate concentration for the Alliance AFBC waste was 0.13 mg/L for barium. Step 2 repetitions resulted in a broad range of concentration, but all values were less than the Step 1 value. The Step 3 repetitions yielded values in the vicinity of the Step 1 value. The total data set for the field cells showed a broad range of concentrations spanning three orders of magnitude, but the three samples selected from the latter part of the period of operation had a much narrower range, from 0.2 to 0.8 mg/L. The lab leaching column with Alliance waste had results comparable to but slightly higher than the field cells during the latter part of the operational period. Both the lab leaching column data and the data for the

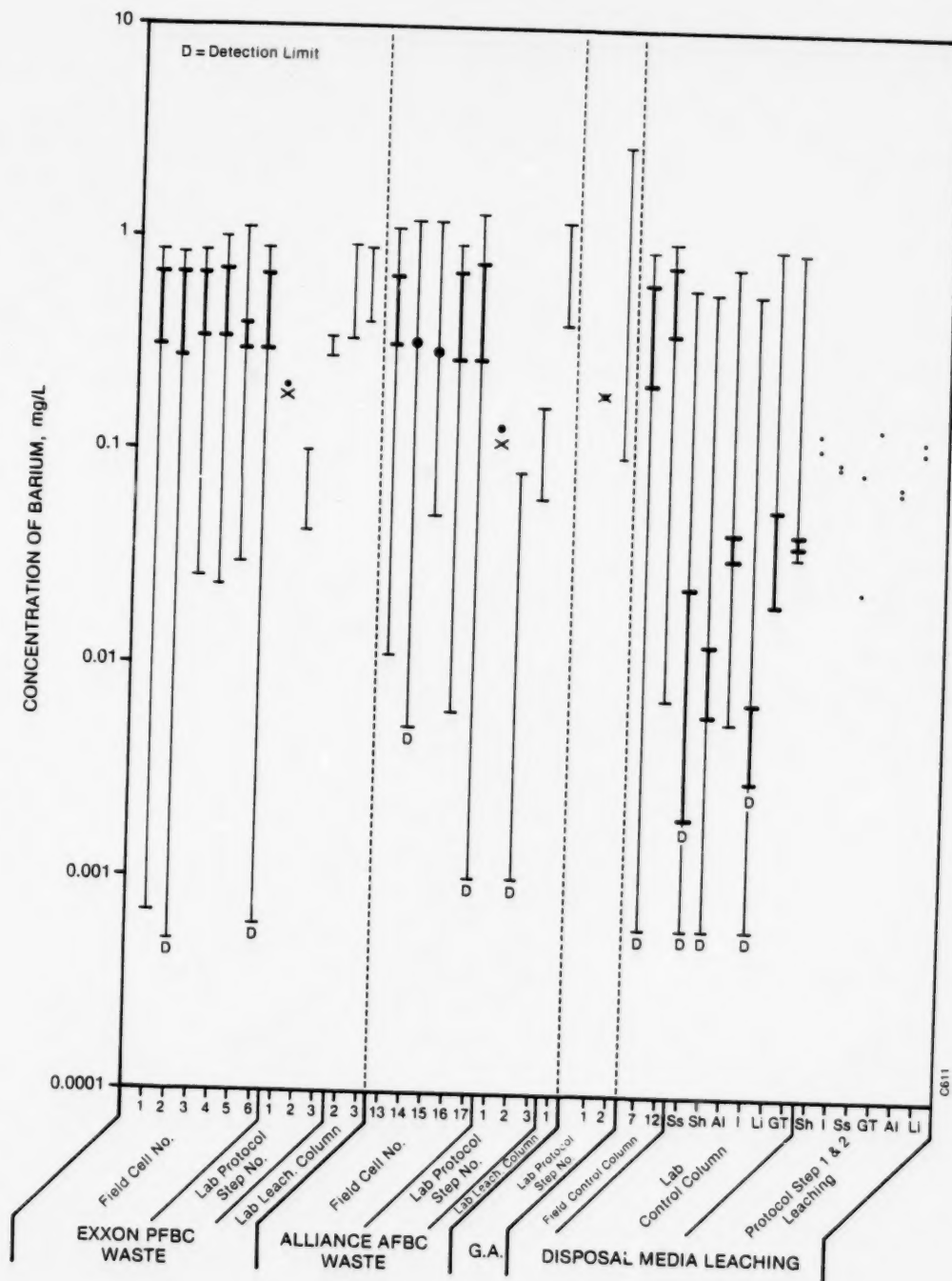


Figure I-6. Concentrations of Barium in Leachates from FBC Wastes and Disposal Media.

latter part of the field cell operation period showed higher barium concentrations than the lab batch leaching results.

The Georgetown AFBC waste had a Step 1 leachate concentration of about 0.2 mg/L for barium. The Step 2 concentrations were higher and ranged from 0.1 to about 3 mg/L.

The leachates from all three FBC wastes had quite similar concentrations of barium for parallel components of the program. The lab protocol Step 1 results were generally in the same range at 0.1 to 0.2 mg/L. All field cells, during the latter period of operation, showed barium concentrations in the 0.2 to 0.8 mg/L range. Thus, the lab studies showed slightly lower concentrations than the latter part of the field studies.

Batch leaching of the disposal media in the lab protocol yielded barium results that were quite consistent for all media; sandstone yielded slightly lower concentrations, and glacial till yielded slightly higher values. The total range of concentrations was quite large and comparable for all the column studies, but clear differences can be seen when the data from the latter part of the periods of operation are examined. The field control cells generally had more than an order-of-magnitude higher concentrations than the lab control columns. Among the lab control columns, the sandstone had the lower and limestone the highest barium concentrations during the latter part of the period of operation.

Comparison of the leaching results from the wastes with the disposal media shows that batch leaching resulted in comparable values for both (0.03 to 0.3 mg/L) and that field cell leaching (latter period of operation) also yielded comparable values (0.2 to 0.8 gm/L) for both. The lab control column results were consistently about an order of magnitude below the field control cells and the field cells containing waste.

I.5.3 Boron

The concentration ranges for boron are plotted in Figure I-7. For the Exxon PFBC waste, the mean Step 1 concentration was 10.5 mg/L. The Step 2 repetitions yielded a range from 1.3 to 17.5 mg/L. The range for Step 3 was higher at 23 to 28 mg/L. The PFBC field cells produced leachate with very comparable concentration ranges. These ranges were from 1.3 to 9 mg/L overall. The PFBC lab leaching columns were comparable to the field cells.

The mean Step 1 boron concentration was about 3.5 mg/L for the Alliance AFBC waste. The ranges for the Step 2 and Step 3 leachates were quite similar and fell between 0.4 and 9 mg/L. The Alliance field cells had relatively large concentration ranges, even for the latter phases of operation, except for the two alluvium-bearing cells (Cells 14 and 15), which had boron concentrations of about 0.2 and 0.3 mg/L, respectively. The range for the interburden and limestone cells (Cells 13 and 16) was about 0.2 to 4 mg/L. For the shale cell (Cell 17), the range was from 0.06 to 4 mg/L. The Alliance lab leaching column also had a broad range of boron concentrations, from detection limit values (0.04 mg/L) to 4 mg/L.

For the Georgetown AFBC waste, the mean Step 1 leachate concentration was about 0.15 mg/L. The range of concentrations for Step 2 leaching was relatively large and extended from the detection limit value (0.04 mg/L) to 2.5 mg/L. Overall, the boron concentration in leachate from the lab protocol was somewhat higher for the Exxon than the Alliance waste; both of these wastes produced higher concentration leachates than did the Georgetown waste. Likewise, the concentrations of boron were higher in Exxon field cell leachates than the Alliance field cell leachates, at least for the latter part of the operational period.

Batch leaching of the disposal media produced mostly detection limit values for boron (about 0.04 mg/L). The exceptions were shale, interburden, and till, which showed concentrations up to 0.1 mg/L. The field control cells and lab control columns had quite variable concentrations and large concentration ranges. The overall range of values was from 0.025 to 7 mg/L

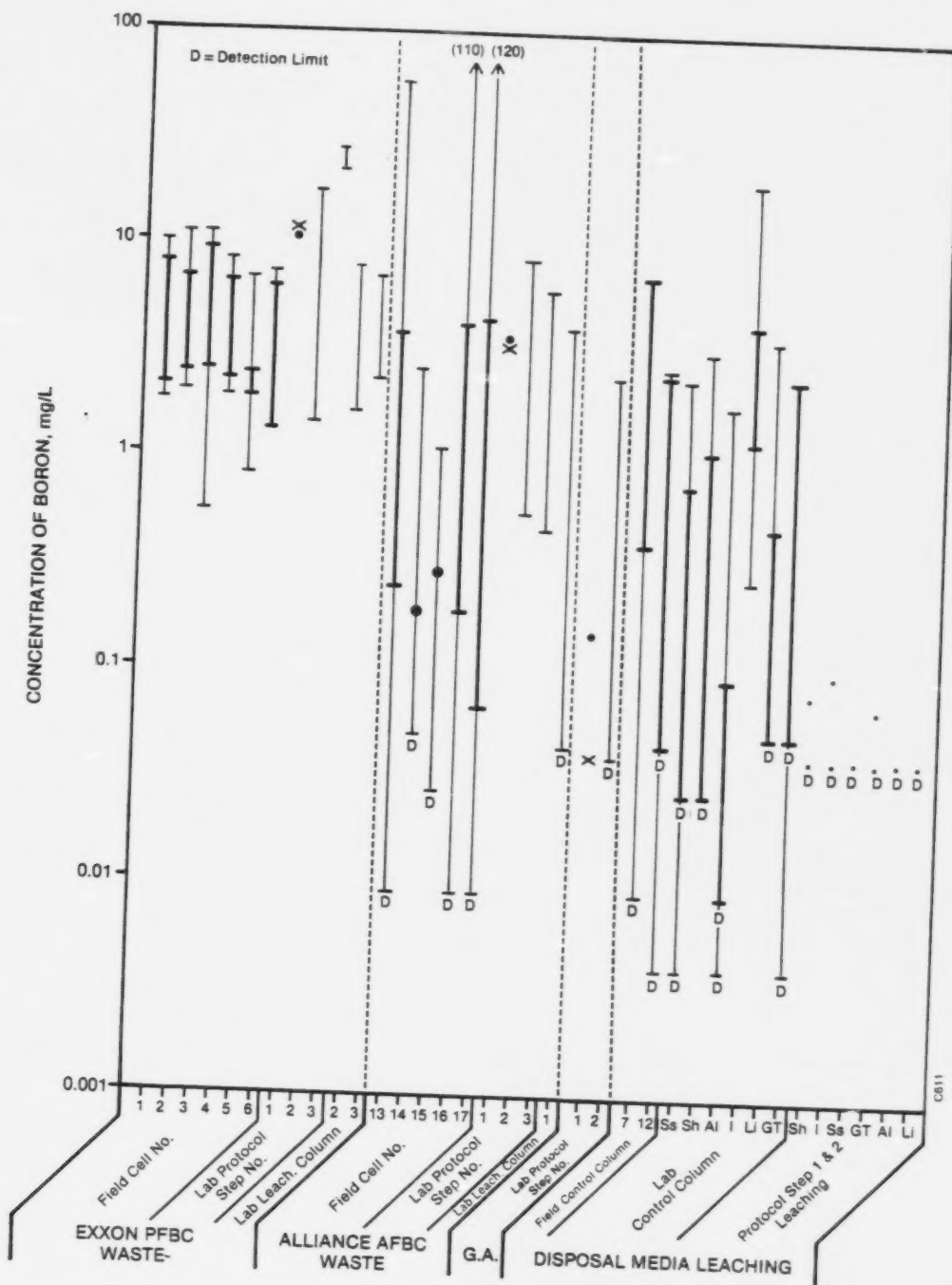


Figure I-7. Concentrations of Boron in Leachates Generated from FBC Wastes and Disposal Media.

for the latter phases of operation. The alluvium control column showed the lowest range of values (0.025 to 0.09 mg/L), and the interburden column showed the highest range (1.1 to 4 mg/L).

In general, the two AFBC wastes produced field cell and lab leaching column leachates with concentrations in the same range as similar leachates (from field control cells and lab control columns) from disposal media alone. The PFBC waste leachates from the field cells and leaching columns were somewhat higher in boron concentrations than similar leachates from both the AFBC waste and the disposal media, or at least the PFBC leachates did not range down to the low values observed for the AFBC waste and disposal media. Step 1 leaching of the Exxon and Alliance waste produced leachates with boron values two orders of magnitude higher than similar leachates from the disposal media.

I.5.4 Cadmium

The concentration ranges for cadmium are shown in Figure I-8. For most components of the study, this element was found at undetectable levels. For the Exxon PFBC waste, the batch equilibration protocol yielded leachates which all had undetected concentrations of cadmium. Field cells 1, 2, and 5 showed some detectable cadmium over the entire period of operation, but the leachate from the latter part of the period of operation had undetectable quantities of leachate.

The mean Step 1 concentration for Alliance AFBC waste was 0.04 mg/L. Step 2 and 3 leachates had comparable ranges, from 0.008 to about 0.1 mg/L. Three of the field cells had detectable quantities of cadmium during the entire period of operation, but the concentrations were very low. The lab control column containing Alliance waste yielded undetectable quantities of cadmium.

The cadmium concentration in leachates from Step 1 leaching of Georgetown AFBC waste was below the detection limit for all samples analyzed. Step 2 leachates ranged from a detection limit value of 0.04 to about 0.14

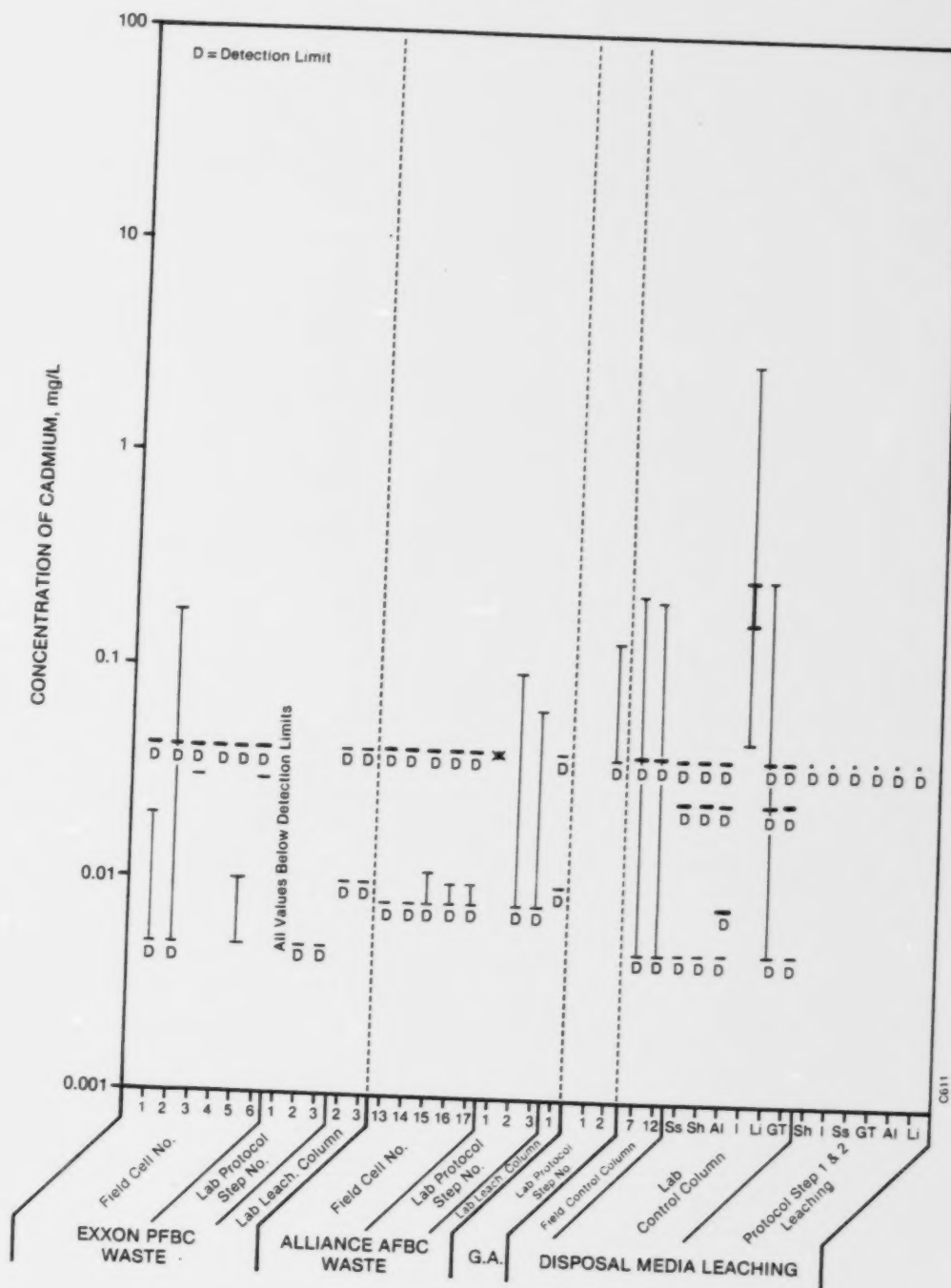


Figure I-8. Concentration of Cadmium in Leachates Generated from FBC Wastes and Disposal Media.

mg/L. The interburden-bearing lab control column yielded leachates with a cadmium concentration from 0.21 to 0.3 mg/L during the latter phases of operation. The range for the limestone column, considering the entire period of operation, was from the 0.04 mg/L detection limit value to 0.3 mg/L. The field control columns with shale and alluvium had concentrations ranging from the 0.04 mg/L detection limit value to about 0.2 mg/L.

I.5.5 Calcium

The concentration ranges for calcium are plotted in Figure I-9. The concentrations found in the lab protocol studies were generally higher than for the field cells and the lab leaching columns. The mean concentration for Step 1 leaching of the Exxon PFBC waste was 1700 mg/L. For Step 2 repetitions, the range was from more than 400 mg/L to 1700 mg/L, and for Step 3, the range was relatively small at just over 1700 mg/L. The concentration ranges for the field cells were quite small and were in the 200 to 700 mg/L range. There was not much difference among the cells, except that the cell containing alluvium had a slightly lower concentration than the others. The ranges for the lab leaching columns were greater than for the field cells, but were in the same concentration range, from 300 to 700 mg/L.

For the Alliance AFBC waste, the Step 1 mean concentration was about 1300 mg/L. The Step 2 and Step 3 ranges were in the same vicinity, from about 1000 to 2500 mg/L. The calcium concentrations in the field cell leachates were generally much lower than in the protocol leachates. The concentration ranges during the latter stages of operation were much more limited than the ranges for the entire operational period. The cells containing interburden, limestone, and shale had calcium concentrations in the leachate of 300 to 500 mg/L during the latter stages of operation. The two cells containing alluvium yielded leachates with less than 100 mg/L of calcium during the latter stages of operation. The lab leaching column containing Alliance waste had leachate concentrations nearer the protocol than the field cell leachate (700 to 1200 mg/L).

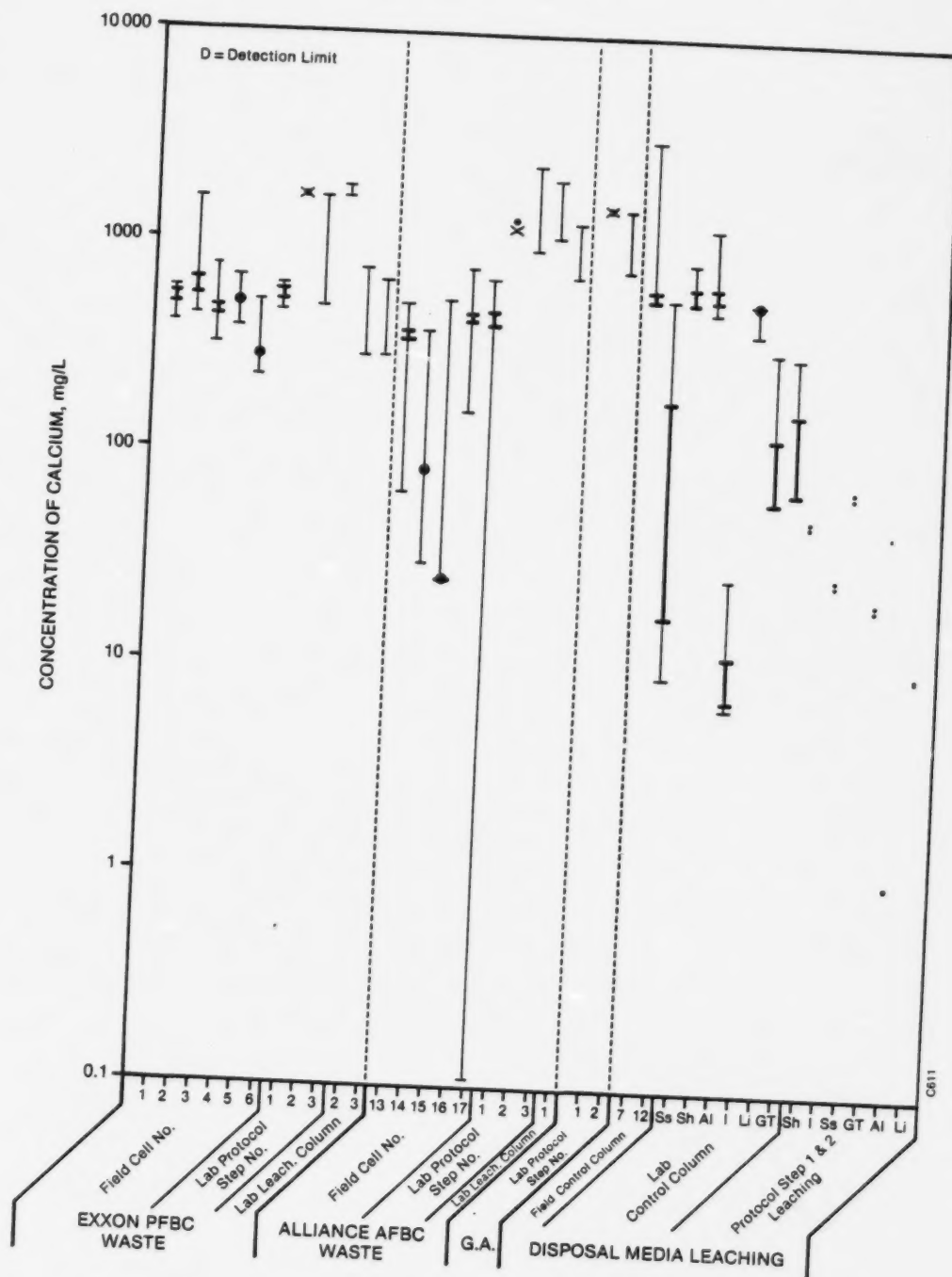


Figure I-9. Concentrations of Calcium in Leachates Generated from FBC Wastes and Disposal Media.

Step 1 leachates from the Georgetown AFBC waste had a mean calcium concentration of about 1500 mg/L. The Step 2 repetitions yielded leachates with concentrations ranging from about 800 to about 1500 mg/L.

The three FBC wastes had remarkably consistent calcium concentration in leachates from parallel components of the study. The Step 1 leachates from all three wastes were quite close at 1300 to 1700 mg/L, and the Step 2 and Step 3 leachates were all generally in the 1000 to 2500 mg/L concentration range. The field cell leachates from the latter part of the period of operation were also very similar; the concentration ranges were quite limited in the 300 to 700 mg/L range. Only the Alliance cells containing alluvium varied from this range, at less than 100 mg/L.

The leachates from the disposal media were somewhat more variable. The lab columns and field cells containing alluvium again yielded calcium values that were generally below the values for other disposal media. Columns and cells containing shale and sandstone had the highest calcium values. There was not a significant difference between the cells operated in the field and the columns that were in the lab. Protocol leaching of the disposal media resulted in leachates with calcium concentrations generally in the 10 to 100 mg/L range.

Overall, the highest calcium values observed were from the lab leaching of the three FBC wastes. The results from the field cells containing Exxon PFBC and Alliance AFBC waste showed very similar calcium concentrations, especially during the latter part of their operation. These ranges were all lower than the ranges from the lab protocol. The leaching results from the lab columns and field cells containing waste were comparable to the columns and cells containing disposal media only for shale and sandstone. But the leachates from waste-bearing cells and columns exceeded the calcium concentrations of similar cells and columns containing only alluvium, limestone, or glacial till. The lab leaching of the waste yielded leachates with calcium concentrations higher than in the leachates from lab leaching of disposal media alone (1300 to 1700 vs. 10 to 100 mg/L).

I.5.6 Chloride

The concentration ranges for chloride are plotted in Figure I-10. the Step 1 leachates from Exxon PFBC waste had a mean concentration of about 4.5 mg/L. Step 2 leachates ranged slightly below this value, with a range of about 1 to 2.5 mg/L. Step 3 concentrations were higher at 15 to 23 mg/L. The Exxon field cells yielded leachates with generally higher chloride concentrations. The field cell containing sandstone (Cell 6) had the overall highest range of concentrations, from 10 to 100 mg/L. One of the shale cells (Cell 2) and the limestone cell (Cell 4) had the lowest ranges during the latter phases of operation, with less than 8 mg/L chloride. The lab leaching columns containing Exxon waste had chloride ranges that were comparable to the field cells.

The mean chloride concentration for Step 1 leachate from the Alliance AFBC waste was 51 mg/L. The Step 2 leachates had much lower concentrations, from about 1.1 to 12 mg/L; Step 3 leachates had a higher range, from 100 to 310 mg/L. The Alliance field cells produced leachates with similar to somewhat higher chloride concentrations than the Step 1 leachate. The shale-bearing cell had the lowest concentration range during the latter phases of operation, from 20 to 60 mg/L. The two cells containing alluvium had the highest concentration. The lab leaching column had leachates with a concentration range of 4 to 40 mg/L.

The Georgetown AFBC waste produced Step 1 leachate with a mean chloride concentration of about 24 mg/L. Step 2 leachates had concentrations ranging from 2 (the detection limit value) to 5.3 mg/L. In general, the Alliance AFBC waste leachates had higher chloride concentrations than the other two wastes. The Step 1 leachates were comparable for the Exxon and Georgetown wastes and were about an order of magnitude below the Alliance waste. The Alliance field cells ranged about an order of magnitude above the Exxon field cells. The waste cells with alluvium had generally lower concentrations than the other cells.

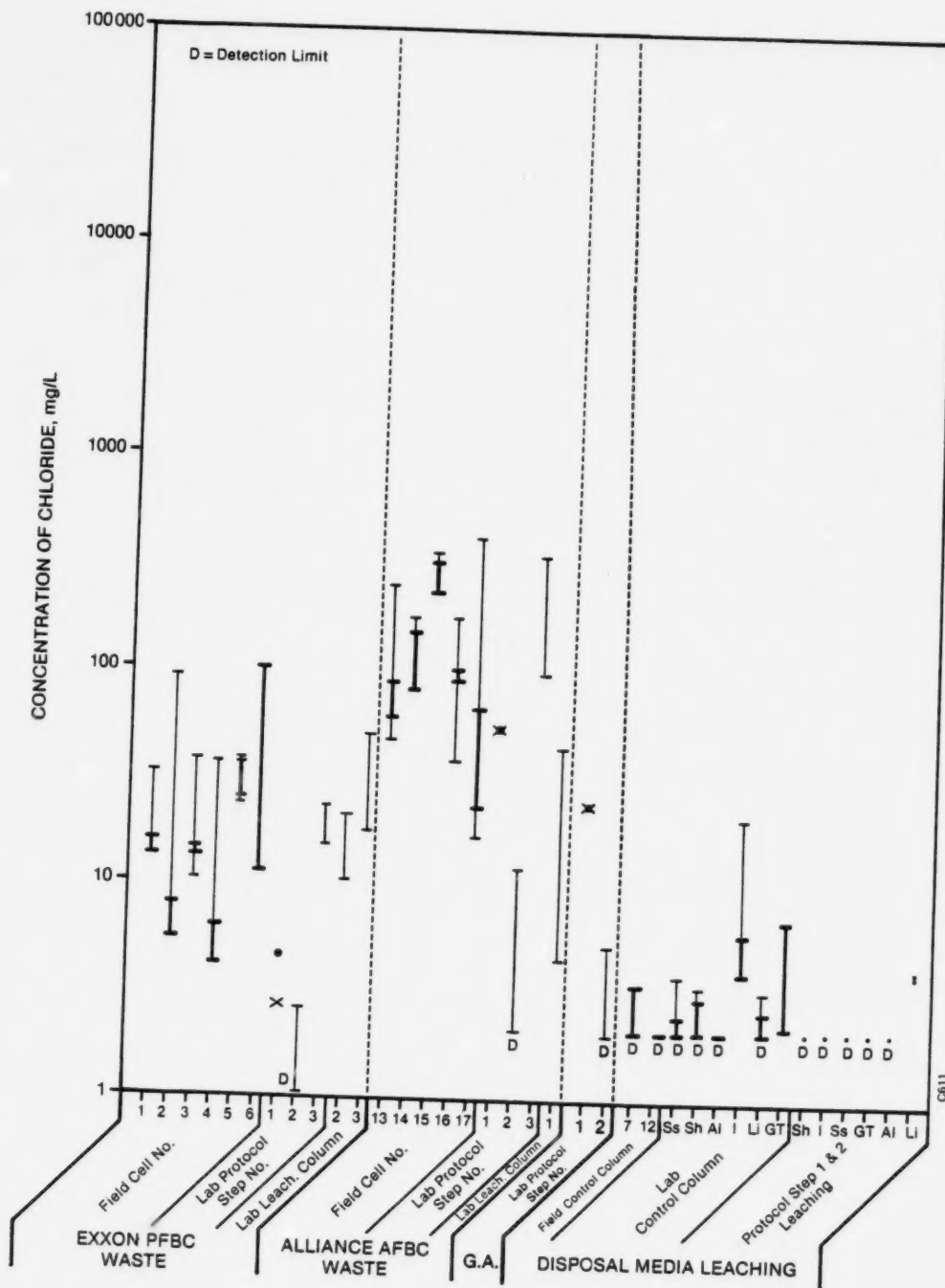


Figure I-10. Concentrations of Chloride in Leachates Generated from FBC Wastes and Disposal Media.

Leaching of the disposal media produced very low concentrations of chloride. All lab batch leaching, lab control columns, and field cells yielded leachates with less than 10 mg/L of chloride, except for some of the leachates from the interburden control column. These leachates are comparable to Step 1 and 2 leaching of the Exxon and Georgetown wastes and to Step 2 leaching of the Alliance waste. Otherwise, the waste leachates generally had higher chloride concentrations than the disposal media leachates.

I.5.7 Chromium

In general, the chromium concentrations were relatively low and were quite close to the detection limits for all phases of the investigation, as shown in Figure I-11. The mean Step 1 leachate concentration for Exxon PFBC waste was 0.09 mg/L. The leachates from repetitions of Step 2 had chromium concentrations ranging from the detection limit value to about 0.21 mg/L. The Step 3 leachates ranged from 0.09 to 0.31 mg/L. During the latter phases of operation, the PFBC field cells yielded leachates with relatively similar concentration ranges, from the detection limit to about 0.075 mg/L. The cells containing limestone and alluvium (Cells 4 and 5) did not range down to the detection limit, but to about 0.02 mg/L during the latter phases of operation. The lab leaching columns containing PFBC waste ranged from the detection limit value to about 0.06 mg/L.

For the Alliance AFBC waste, the mean Step 1 leachate concentration was 0.12 mg/L. The Step 2 and Step 3 leachates had similar concentrations, with an overall range of 0.023 to 0.3 mg/L. The Alliance field cells with interburden, limestone, and shale (Cells 13, 16, and 17) had similar leachate composition with respect to chromium during the latter phases of operation. The concentration ranges for these cells were from detection limit values (0.005 mg/L) to about 0.04 mg/L. One of the cells containing alluvium had undetectable concentration of chromium, and the other cell had a concentration of about 0.045 mg/L. The lab leaching column with Alliance waste had a relatively large range from detection limit values (0.005 mg/L) to 0.09 mg/L.

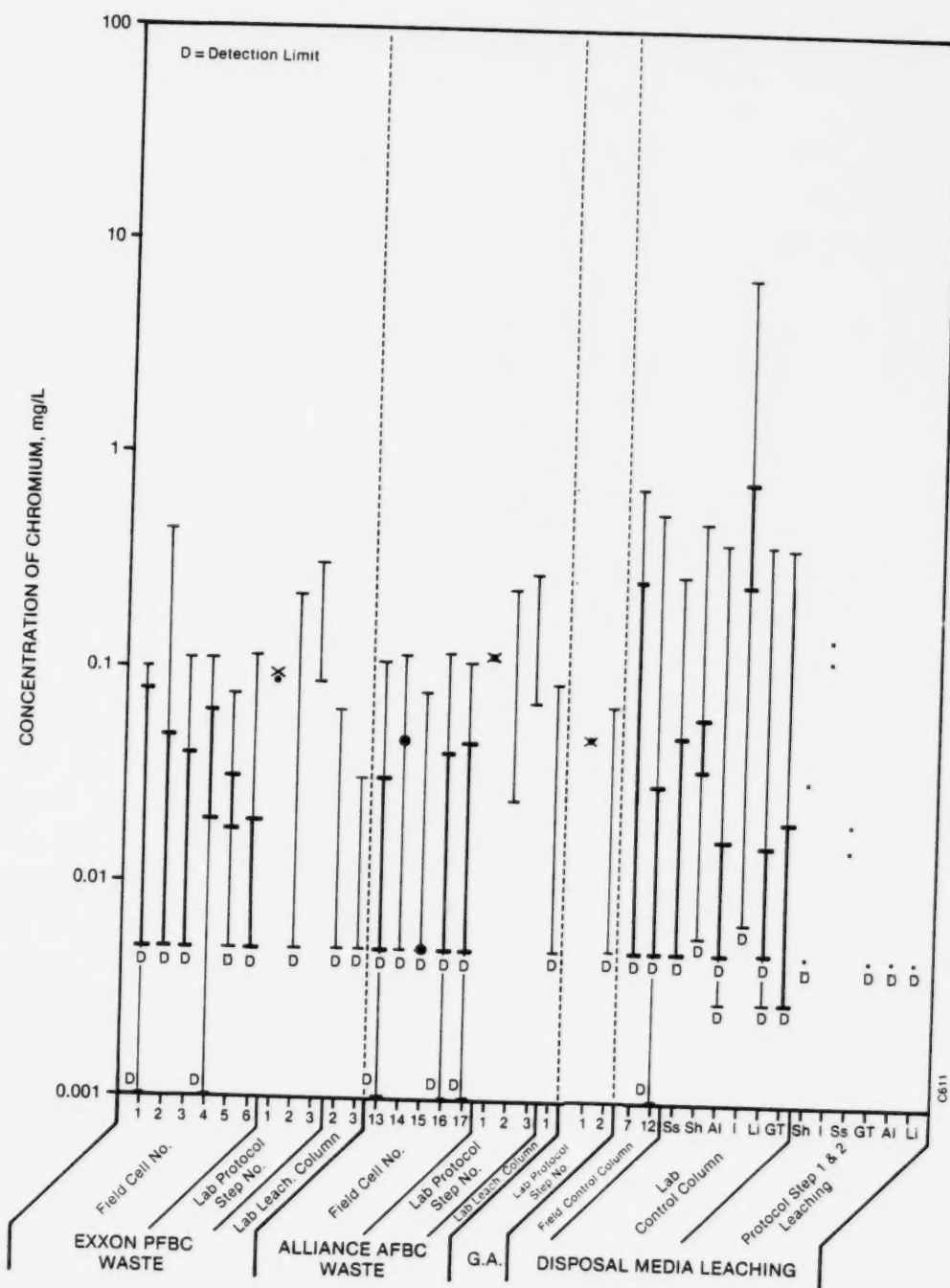


Figure I-11. Concentrations of Chromium in Leachates Generated from FBC Wastes and Disposal Media.

The mean Step 1 leachate concentration for the Georgetown AFBC waste was 0.05 mg/L. The range of concentration for Step 2 was from detection limit values to about 0.07 mg/L. The batch leaching results overall were quite similar for the Exxon and Alliance waste; these results were generally somewhat higher than the results for the Georgetown waste, especially for the Step 1 leachate. There was little or no difference in the chromium concentrations in leachates from the Exxon and Alliance wastes. The results from the lab leaching columns were also very comparable for the two wastes.

Batch leaching of the disposal media resulted in undetectable chromium concentrations for the shale, till, alluvium, and limestone media. The interburden yielded leachates in the 0.1 to 0.2 mg/L range, and the sandstone produced leachates with 0.01 to 0.02 mg/L for chromium. During the latter phases of operation, the shale-bearing field control cell yielded leachates with a concentration range of 0.005 to 0.25 mg/L. The range for the alluvium-bearing cell was from 0.005 to 0.03 mg/L. The lab control columns containing sandstone, alluvium, limestone, and till had chromium concentrations ranging from detection limit values to 0.05 mg/L. The shale column, during the latter phases of operation, had a concentration range from 0.03 to 0.06 mg/L. The interburden column had higher concentrations, with a range of 0.25 to 0.8 mg/L.

In general, Step 1 leaching of the wastes produced leachates with a chromium concentration about an order of magnitude higher than equivalent leaching of the disposal media. The waste-bearing field cells and leaching columns had very similar chromium concentrations to their counterparts containing disposal media only.

I.5.8 Cobalt

The concentration range plots for cobalt are shown in Figure I-12. The wide spread between the mean and median values for the Step 1 leachates from the Exxon PFBC waste occurred because a large fraction (8) of the 12 samples analyzed had undetectable concentrations (<0.15 mg/L), whereas the remaining 4 samples had a mean concentration of 1.6 mg/L. Step 2 and Step 3 leachates

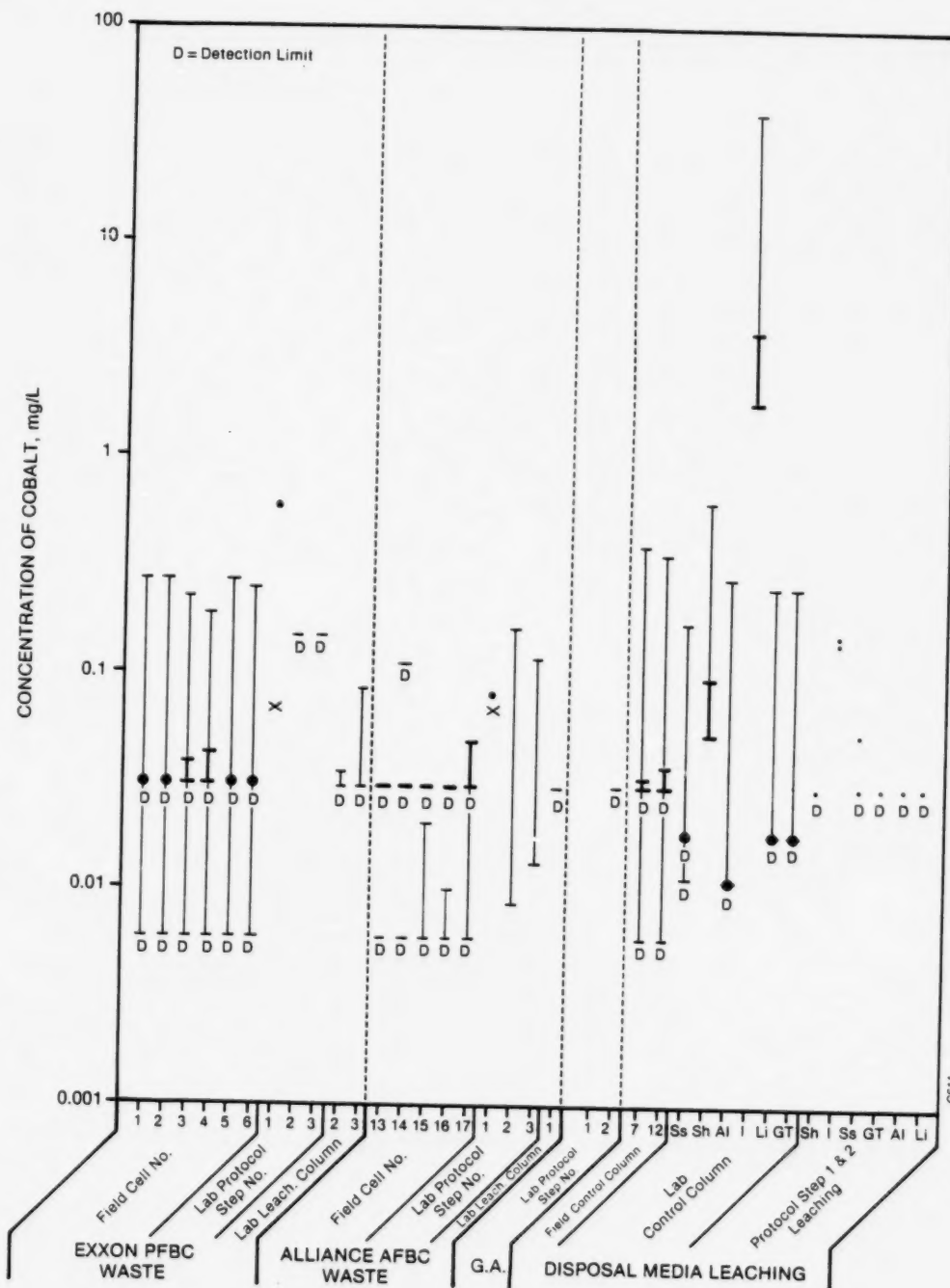


Figure I-12. Concentrations of Cobalt in Leachates Generated from FBC Wastes and Disposal Media.

from the Exxon waste had undetectable cobalt concentrations. The overall cobalt concentrations in the leachates from the Exxon field cells ranged from detection limit values (0.006 mg/L) to as high as 0.3 mg/L. During the latter phases of operation, the cobalt concentrations were undetectable at 0.03 mg/L (for four of the field cells) or nearly undetectable (for two of the cells). The Exxon lab leaching columns also had low or undetectable cobalt concentrations.

The mean Step 1 leachate concentration for the Alliance AFBC waste was 0.08 mg/L. Repetition of Step 2 resulted in a cobalt concentration range of from 0.008 to 0.15 mg/L; Step 3 repetitions yielded leachates with a concentration range from 0.01 to 0.11 mg/L. The Alliance field cells had generally very low to undetected cobalt concentrations, as did the lab leaching column.

Step 1 and Step 2 leaching of the Georgetown AFBC waste produced leachates with undetectable quantities of cobalt.

Leaching of the disposal media also resulted in very low to undetectable cobalt concentrations. Batch leaching of the media yielded leachates with detectable concentrations only for interburden, which had about 0.14 mg/L cobalt. The field control cells, during the latter part of the operational period, yielded leachates with 0.03 to 0.04 mg/L of cobalt. The lab control columns had undetectable concentrations (or nearly so) for four of the six media. Leachate from the shale column had concentrations ranging from 0.05 to 0.1 mg/L, and the interburden leachate had concentrations from 1.8 to 3.8 mg/L.

Comparisons of leachate from the waste with those from the disposal media did not yield much of value, since almost all of the leaching investigations showed such low cobalt concentrations. About all that can be stated is that Step 2 leachates from the Alliance AFBC waste had cobalt concentrations comparable to the field control cells and the shale-bearing lab control column. The Step 2 Alliance leachates were about two orders of magnitude below the interburden-bearing lab control column.

I.5.9 Copper

The ranges of copper concentrations for all phases of the program are shown in Figure I-13. The initial suite of Step 1 leachates from the Exxon PFBC waste had undetectable levels of copper (<0.005 mg/L), but subsequent leachates had a mean concentration of 0.058 mg/L (Appendix J). Step 2 repetitions also yielded leachates with undetectable copper concentration. The Step 3 repetition ranges from the 0.005 mg/L detection limit to 0.008 mg/L. Most of the PFBC field cell leachates had copper concentrations below the 0.005 mg/L detection limit, but some of the samples ranged up to 0.15 mg/L. The PFBC lab leaching columns exhibited similar behavior, with a range from <0.005 to 0.1 mg/L.

Lab batch leaching of the Alliance AFBC waste yielded leachates with somewhat higher copper concentrations; the mean Step 1 concentration was 0.14 mg/L, and the Step 2 repetitions produced leachates with a concentration range from 0.023 to 0.31 mg/L. The Step 3 leachates ranged from about 0.022 to 0.2 mg/L. The Alliance field cells produced leachates with copper concentrations ranging from less than 0.001 to 0.11 mg/L, as did the lab leaching column containing Alliance waste.

Step 1 leaching of the Georgetown AFBC waste yielded a copper concentration below the detection limit for four of the six samples. The mean of the other two samples was 0.08 mg/L (Appendix J). The Step 2 concentration ranged from less than 0.005 to about 0.1 mg/L. The lab protocol leaching produced higher concentrations from the Alliance waste than from the Exxon or the Georgetown waste. Otherwise, the wastes yielded leachates with comparable copper concentrations.

Batch leaching of the disposal media resulted in leachates with copper concentrations at or below the 0.005 mg/L detection limit for all media except the interburden, which yielded concentrations of 0.8 to 0.9 mg/L. The lab control columns and field cells containing disposal media had low copper concentrations comparable to the field cells and lab columns containing waste. Again, the interburden yielded higher concentrations, with a

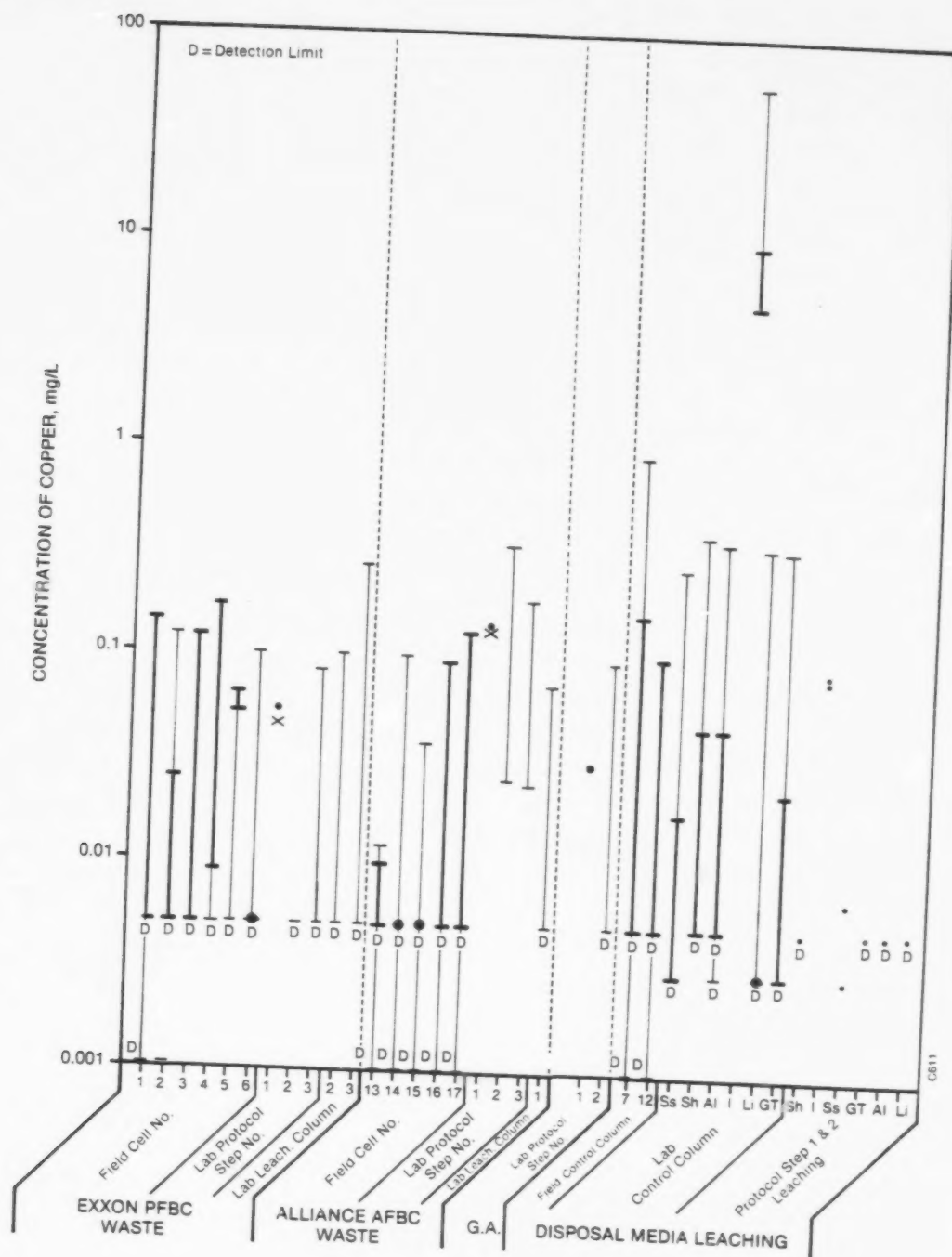


Figure I-13. Concentrations of Copper in Leachates Generated from FBC Wastes and Disposal Media.

range of 4 to 10 mg/L of copper during the latter phases of column operation.

I.5.10 Fluoride

The concentration range chart for fluoride is shown in Figure I-14. The Step 1 leachates from the Exxon PFBC waste had a mean concentration of about 0.9 mg/L. The Step 2 leachate concentration range was somewhat lower (0.2-0.6 mg/L). The Step 3 concentration range was from about 0.7 to about 4 mg/L. The leachate concentrations for the field cells were very similar; the ranges were from 0.1 to 0.3 mg/L for the latter stages of operation. The lab leaching columns had slightly higher ranges, from 0.2 to 0.7 mg/L.

The Step 1 leachate from Alliance AFBC waste had a mean fluoride concentration of 0.25 gm/L. The Step 2 and Step 3 leachate concentration ranges were about 0.08 to 0.3 mg/L and 0.07 to 0.35 mg/L, respectively. The field cell results were again quite consistent, with a composite range of 0.09 to 0.3 mg/L. The lab leaching column containing Alliance waste had a range of 0.2 to 0.5 mg/L fluoride.

The Georgetown AFBC waste had a mean Step 1 fluoride value of 0.16 mg/L, and Step 2 values ranged from 0.05 to 0.15 mg/L. Comparison of the three FBC wastes shows that the Step 1 and Step 2 leaching yielded similar leachates for the Alliance and Georgetown wastes, with concentrations ranges of about 0.05 to 0.35 mg/L. The Exxon lab leaching results showed a somewhat higher fluoride concentration of 0.2 to 3.5 mg/L. The field cell results were very similar for the Exxon and Alliance wastes. So also were the lab leaching column results for the two wastes.

Batch leaching of the disposal media resulted in fluoride concentrations ranging over slightly more than an order of magnitude, from 0.08 to about 1.1 mg/L. The lab control columns containing interburden and limestone had fluoride values of 1 to 3 mg/L; the other lab control columns and field control cells had generally lower concentrations (from 0.05 to 0.11

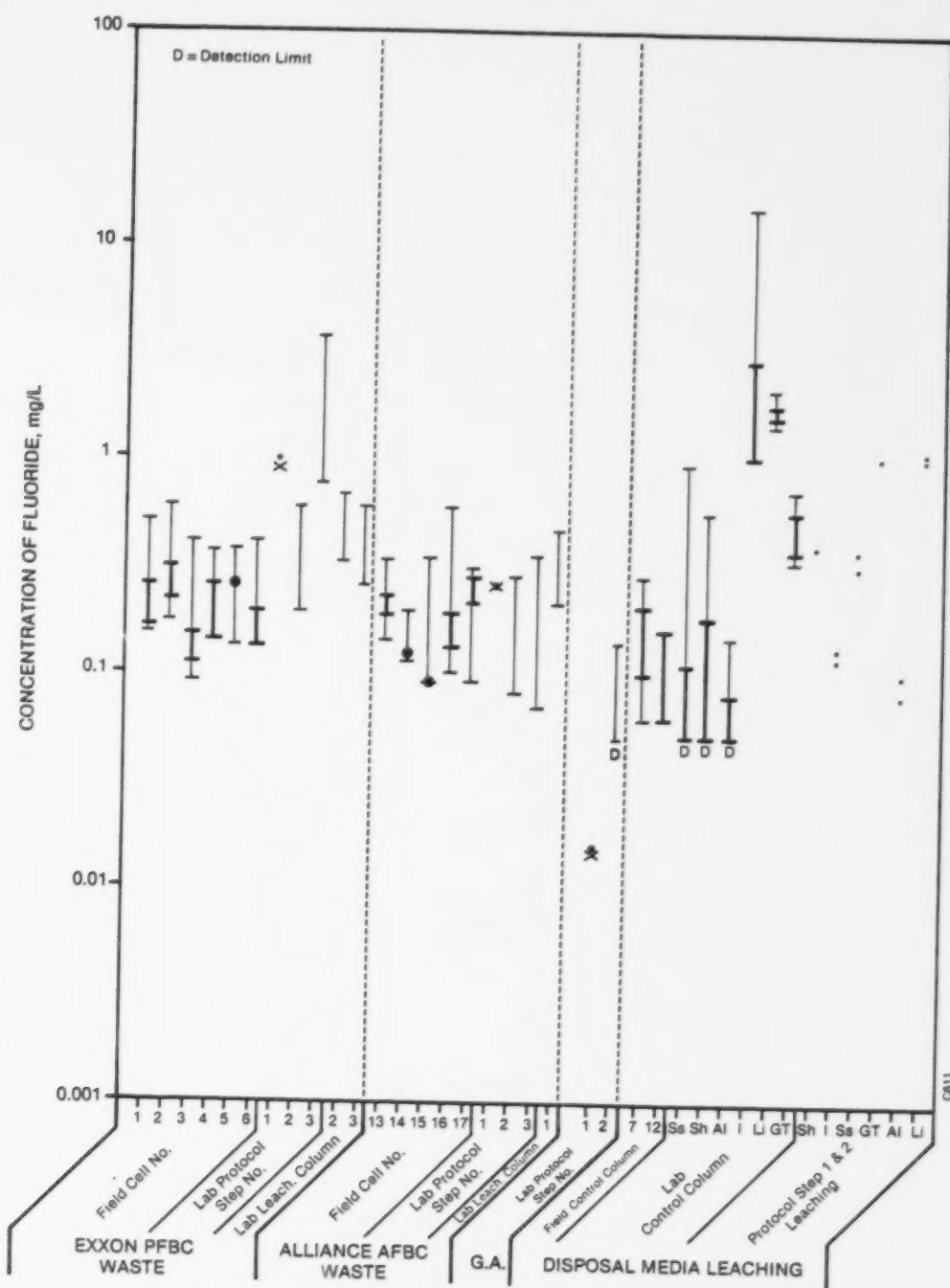


Figure I-14. Concentrations of Fluoride in Leachates Generated from FBC Wastes and Disposal Media.

mg/L). The control column with glacial till yielded leachate with concentrations of 0.35 to 0.6 mg/L.

The batch leaching results from the wastes and disposal media were quite comparable and fell generally in the 0.1 to 1.0 mg/L range for all wastes and all media. The interburden and glacial till control columns had generally higher concentrations than the waste-bearing field cells and lab control columns, whereas the sandstone, shale, and alluvium control columns had lower concentrations than the waste-bearing cells and columns.

I.5.11 Iron

Plots of the concentration ranges for iron are shown in Figure I-15. The mean Step 1 leachate concentration for Exxon PFBC waste was 0.15 mg/L. Step 2 leachates ranged from 0.04 to 0.4 mg/L, and Step 3 leachates ranged from 0.12 to about 0.2 mg/L. The ranges of concentration from the PFBC field cells were consistent for all the cells and were all below 1 mg/L. For the latter part of the period of operation, the concentrations for all cells were between 0.035 and 0.2 mg/L. The PFBC lab leaching columns produced leachates with iron concentrations comparable to the leachates from the latter part of the field cell operation.

The Alliance AFBC waste had a mean Step 1 leachate concentration of about 0.08 mg/L. Both Steps 2 and Step 3 leachates had a relatively broad range of concentrations, with detection limit values (0.007 mg/L) to 0.2 mg/L for Step 2 and 0.02 mg/L to 0.1 mg/L for Step 3. The Alliance field cells, during the latter phases of operation, had consistent concentration ranges from 0.035 to 0.10 mg/L. The lab leaching column containing Alliance AFBC waste had a concentration range similar to the leachate from the latter phases of field cell operation.

Step 1 leachates from the Georgetown AFBC waste had iron concentrations at or below the 0.04 mg/L detection limit. Step 2 leachates ranged from the detection limit values to 0.07 mg/L.

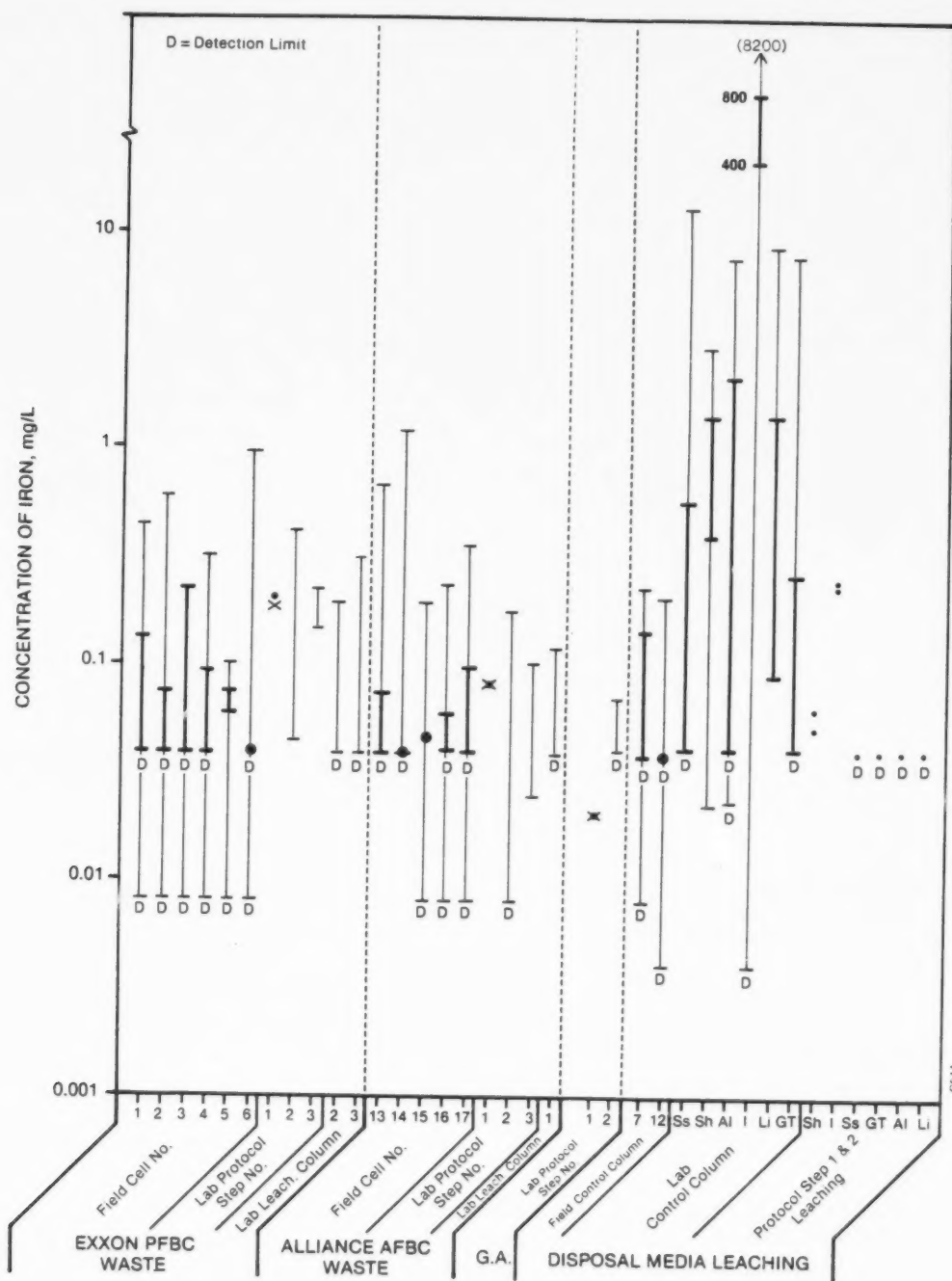


Figure I-15. Concentrations of Iron in Leachates Generated from FBC Wastes and Disposal Media.

The laboratory leachates from the Exxon PFBC waste had generally slightly higher concentration than leachates from the two AFBC wastes. The PFBC and Alliance AFBC field cells, during the latter part of the operational period, produced leachate with very similar iron concentration. The lab leaching columns containing Exxon and Alliance waste also produced leachates with comparable concentrations.

Disposal media leaching did not produce as consistent results; overall the ranges of concentration were quite large, even for the latter phases of lab column and field cell operation. Batch leaching of the media yielded leachates with iron concentrations at or below the 0.04 mg/L detection limit for four of the media. The shale leachate had concentrations of 0.04 to 0.06 mg/L, and the interburden leachate was at about 0.24 mg/L. These batch leaching values are comparable to or below similar values when batch leaching of the waste. The field cells and lab control columns containing disposal media generally had leachates with comparable or higher iron concentrations than leachates from counterpart cells and columns containing waste.

I.5.12 Lithium

The concentration range plots for lithium are shown in Figure I-16. Lithium was not analyzed in the Step 1, 2 and 3 leachates for the Exxon PFBC wastes. Four of the PFBC field cells had quite similar lithium concentrations during the latter stages of operation, from 0.17 to 0.4 mg/L. Cell 2, one of the cells containing shale, had lower concentrations ranging from the detection limit (0.002 mg/L) to 0.11 mg/L. Cell 5, containing alluvium, had lithium concentrations ranging from 1 to 1.5 mg/L. The lab leaching columns with PFBC wastes showed a very large concentration range, from the 0.002 mg/L detection limit to about 4 mg/L.

The mean Step 1 leachate concentration for Alliance AFBC was 0.36 mg/L of lithium. Step 2 repetition produced generally lower concentrations in the 0.12 to 0.34 mg/L range, whereas the Step 3 leachates had generally higher concentrations in the 0.5 to 2 mg/L range. The ranges of lithium concentration in leachates from the field cells were from 0.5 to 1.1 mg/L

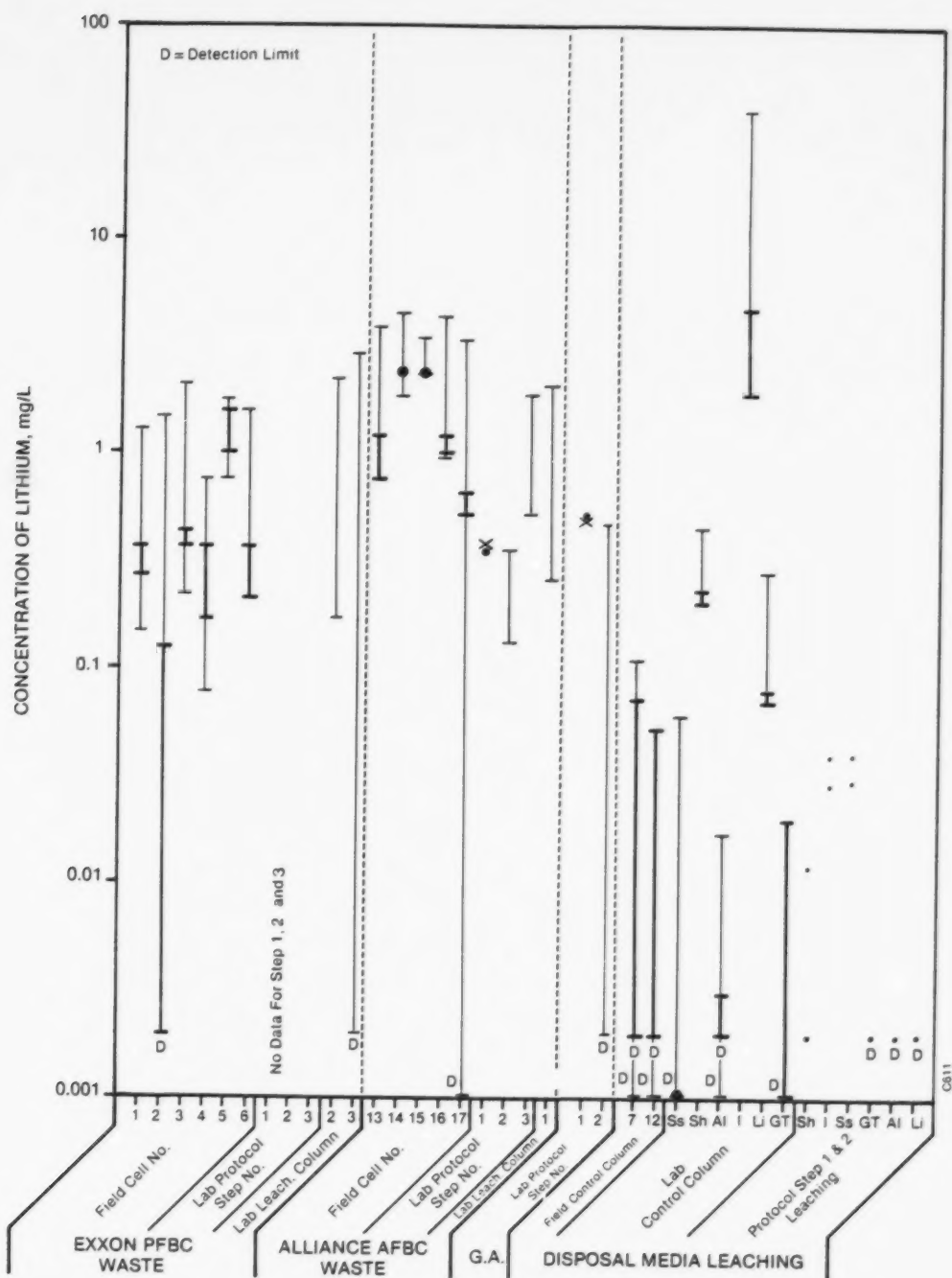


Figure I-16. Concentrations of Lithium in Leachates Generated from FBC Wastes and Disposal Media.

for Cells 13, 16, and 17 (containing interburden, limestone, and shale); the concentration was about 2.3 mg/L for the duplicate cells containing alluvium (Cells 14 and 15) during the latter phases of the operational period. The lab leaching column containing Alliance waste had a range of 0.25 to 2 mg/L.

For the Georgetown AFBC waste, the mean Step 1 concentration was 0.5 mg/L. The Step 2 repetitions yielded leachates with a very broad range of concentration, from the detection limit value (0.002 mg/L) to 0.5 mg/L. Overall, the batch leaching results were quite comparable for all three FBC wastes. The Alliance field cells had generally higher lithium concentrations (during the latter phases of operation) than the Exxon field cells, although the range for the Exxon/alluvium cell (Cell 5) was above the range for the Alliance/shale cell (Cell 17). The lab leaching columns containing Exxon and Alliance waste produced leachate with similar concentration ranges.

The results of leaching of the disposal media were less consistent than for the wastes. Both field control cells which contained shale and alluvium (Cells 7 and 12) had a broad range of concentration, even during the latter phases of operation, that were from 0.002 to about 0.07 mg/L. The alluvium, limestone, and glacial till control columns all had lithium concentration ranges below 0.1 mg/L. The interburden control column had a range of 2 to 5 mg/L. Batch leaching of the disposal media yielded leachate with undetectable quantities (<0.002 mg/L) of lithium for the till, alluvium, and limestone. The shale also had low lithium concentrations (one at detection limit and one at 0.011 mg/L). The interburden and sandstone yielded leachate with 0.03 to 0.05 mg/L of lithium.

In general, the concentration of leachates from the waste-bearing components of the study were higher than the leachates from the disposal media alone. The exception to this generalization were the interburden control column, which yielded higher-concentration leachates than the wastes, and Cell 2 (containing PFBC waste and shale), which had a lithium concentration

range comparable to the disposal media. Batch leaching of the wastes produced leachate with at least an order of magnitude higher concentrations than similar leaching of the disposal media.

I.5.13 Magnesium

The concentration range plots for magnesium are shown in Figure I-17. Overall, the analytical results for magnesium varied over a relatively large range. The mean Step 1 concentration in leachate from Exxon PFBC waste was about 1.5 mg/L. Step 2 repetitions resulted in concentrations ranging from 0.1 to 6 mg/L. The range for Step 3 repetitions was smaller (0.3 to 1.5 mg/L) but still significant. The overall concentration ranges for leachates from the PFBC field cells were large and overlapping, but some distinctions can be seen when the latter part of the record is considered. The lithium values in leachates for all field cells exceeded the Step 1 value and were generally in the 1 to 12 mg/L range. The lab leaching columns containing PFBC waste yielded results consistent with the field cells.

The mean Step 1 magnesium concentration for the Alliance AFBC waste was about 0.8 mg/L. Steps 2 and 3 yielded leachates with a considerable range of concentration (0.03 to 2.5 mg/L). The Alliance field cells also showed relatively broad ranges of magnesium concentration. The latter part of the record showed a range of 0.15 to 0.8 mg/L for the limestone and shale cells and from 1 to 4 mg/L for the interburden and the two alluvium cells. The lab leaching column containing Alliance waste showed a relatively narrower concentration range comparable to the limestone and shale field cells.

The Georgetown AFBC Step 1 leachate had a mean concentration of 2.7 mg/L. The Step 2 repetitions had a range of 0.15 to about 6 mg/L. Generally speaking, the Alliance AFBC waste yielded lower magnesium values than the Exxon PFBC waste. The Step 1 values were relatively close, but overall, the PFBC field cells yielded higher concentration than the Alliance field cells. The Georgetown AFBC waste appeared to have higher lab leaching magnesium values than either the Exxon or Alliance waste.

The disposal media had very large ranges of magnesium concentration overall, but the latter part of the record for the lab columns and field cells is more instructive. Batch leaching of the media resulted in concentrations in the 2 to 23 mg/L range, which is slightly higher than the values obtained for the three FBC wastes. In the lab columns and field cells, the latter part of the record shows high magnesium concentrations (>200 mg/L) for the shale, sandstone, and interburden columns and cells. Limestone and glacial till (40 to 70 mg/L) were also high. The cell and column containing alluvium were generally lower in magnesium concentration than the other cells and columns.

Most of the disposal media leachates had higher magnesium concentrations than the waste leachates. Batch leaching of the media resulted in generally higher concentrations than similar leaching of the wastes. Likewise, the media-bearing field cells and control columns had higher magnesium values than the waste-bearing cells and columns, except that the alluvium-bearing cell and column yielded leachates with magnesium concentrations comparable to the values from the wastes.

I.5.14 Manganese

The concentration range plots for manganese are shown in Figure I-18. For Step 1 leaching of the Exxon PFBC waste, seven of the twelve values were at or below the detection value; the mean concentration for the remaining five values was 0.01 mg/L. Step 2 and 3 leaching yielded leachates with undetectable quantities of manganese. During the latter phases of operation, two of the PFBC waste-bearing field cells (Cells 1 and 2 containing shale) yielded leachates with undetectable quantities of manganese (<0.006 mg/L). Cell 3, containing glacial till, had concentrations ranging from undetectable levels to 0.02 mg/L, and Cell 5, with alluvium, yielded leachates with manganese levels ranging from undetectable levels to 0.11 mg/L. The limestone-bearing cell (Cell 3) had manganese concentrations from 0.01 to 0.1 mg/L, and the cell with sandstone (Cell 6) ranged in manganese concentration from 0.03 to 0.06 mg/L. One of the lab leaching columns had

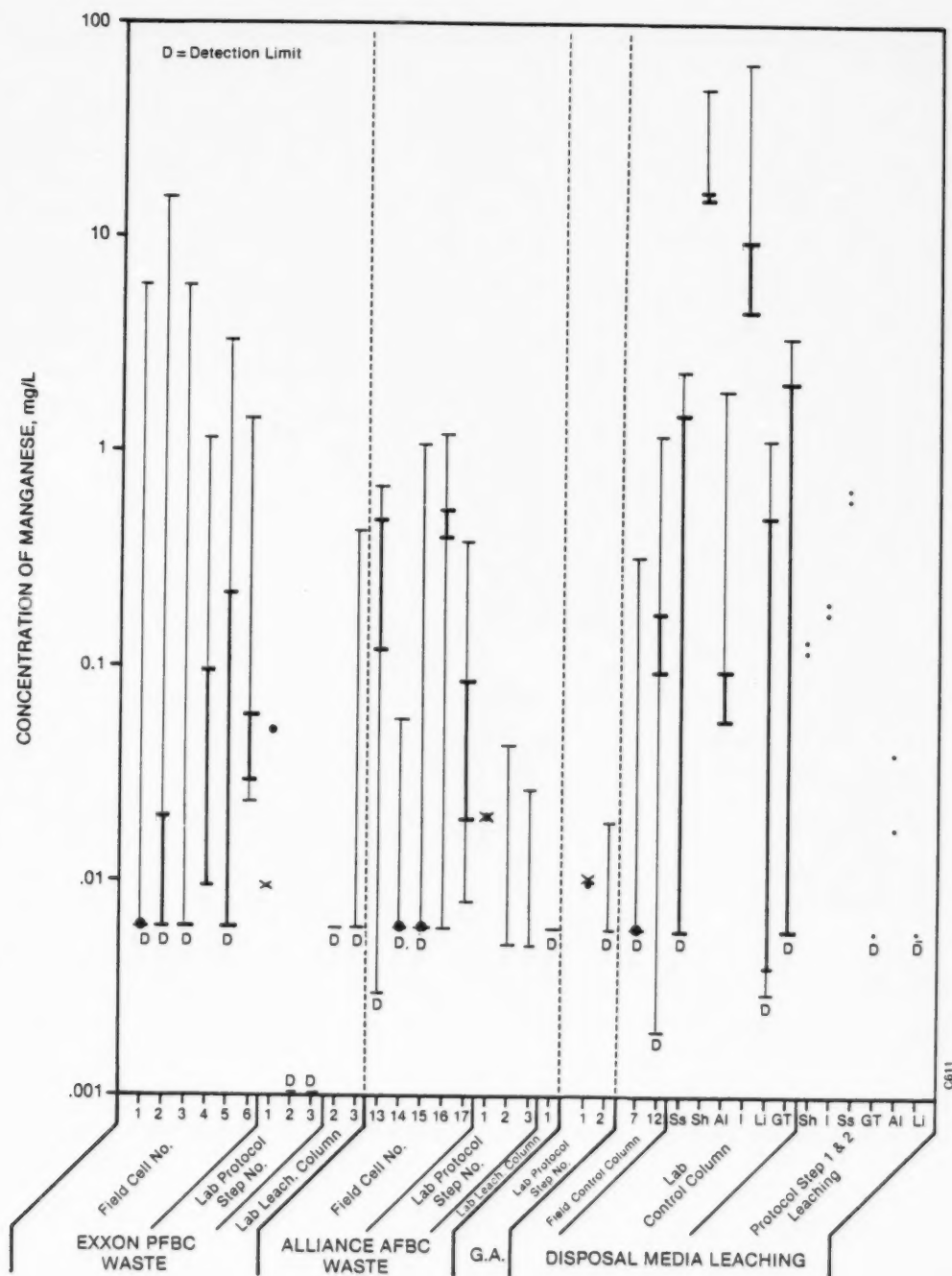


Figure I-18. Concentrations of Manganese in Leachates Generated from FBC Wastes and Disposal Media.

undetectable quantities of manganese, and the other column ranged from undetectable levels to 0.4 mg/L.

The mean Step 1 leachate concentration for the Alliance AFBC waste was 0.02 mg/L manganese. Repetition of Step 2 yielded leachates with concentrations ranging from 0.005 to 0.04 mg/L. Step 3 repetitions produced leachates in the 0.007 to 0.025 mg/L range. Two of the Alliance waste-bearing field cells yielded undetectable quantities of manganese (Cells 14 and 15, containing alluvium). Cell 13, containing interburden, and Cell 16, containing limestone, had manganese concentrations of 0.11 to 0.5 mg/L and 0.4 to 0.52 mg/L, respectively. The remaining cell was in the 0.02 to 0.09 mg/L range. The lab leaching column produced undetectable quantities of manganese.

The Georgetown AFBC waste had two Step 1 leachates at or below the detection limit. The mean concentrations of the other four leachates was 0.16 mg/L. The general range for Step 2 was from undetectable quantities to 0.022 mg/L. Two of the field cells containing Alliance AFBC waste yielded higher manganese concentrations than the Exxon PFBC cells. Otherwise, the results from the three wastes were quite comparable.

Batch leaching of the shale, interburden, and sandstone yielded leachates in the 0.1 to 0.7 mg/L range. Similar leaching of the glacial till and limestone produced undetectable quantities of manganese. Alluvium produced intermediate manganese levels. Field cell and lab column leaching of the media produced a wide variety of results even during the latter part of the operational period. The lowest concentrations were observed in the cells containing alluvium, (undetectable quantities), and the highest were observed in the lab control column containing shale (13-15 mg/L).

Batch leaching of the shale, interburden, and sandstone yielded higher manganese concentrations than similar leaching of the FBC wastes. Batch leaching of the till and limestone produced lower concentrations than in the

waste. The control column containing shale and interburden produced leachates higher in manganese concentrations than any of the other field cells containing waste and disposal media.

I.5.15 Molybdenum

Figure I-19 shows the concentration ranges for molybdenum. The mean Step 1 leachate concentration for Exxon PFBC waste was about 2.5 mg/L, but undetectable molybdenum concentrations were found during repetitions of Step 2. Molybdenum was not analyzed in the Step 3 leachate. During the latter phases of the operational period, the Exxon field cells ranged generally from 0.01 to 0.11 mg/L of molybdenum. The cell containing glacial till produced the highest concentration range (0.05 to 0.18 mg/L), and one of the cells containing shale had the lowest range (0.01 to 0.04 mg/L). The concentration ranges of the lab leaching columns containing Exxon waste were from about 0.04 to 0.80 mg/L, a relatively large range.

For the Alliance AFBC waste, the mean Step 1 leachate concentration for molybdenum was 0.42 mg/L. The range of concentrations from Step 2 was lower (0.01 to 0.28 mg/L), and the range from Step 3 was higher (0.5 to 0.7 mg/L). The Alliance field cells (latter part of operational period) yielded leachates in the 0.5 to 1.2 mg/L range, a relatively narrow range. Interestingly, the cell containing interburden (Cell 13) had the lowest molybdenum concentration during the latter operational phases. The alluvium-bearing cells (Cells 14 and 15) had the highest concentrations. The lab leaching column had a concentration range comparable to the waste-bearing field cells.

The Georgetown AFBC waste had four Step 1 leachate concentrations at the detection limit value (0.01 mg/L). The mean concentration of the other two leachates was 0.053 mg/L. The Step 2 concentration range was from the detection limit value (<0.01 mg/L) to 0.05 mg/L.

For the Exxon waste, the Step 1 leachate had higher molybdenum concentrations than the field cells, but the reverse was true for the Alliance

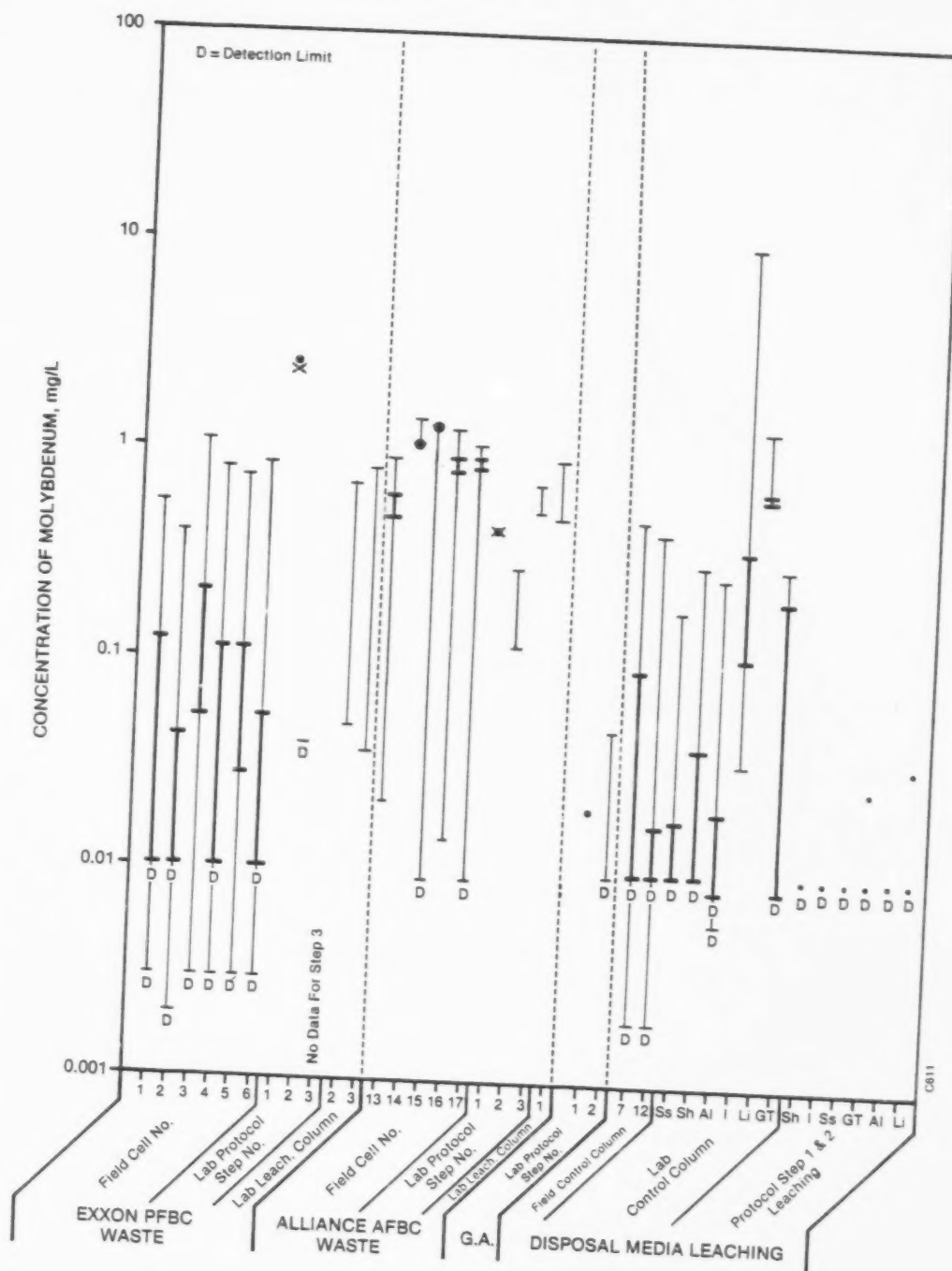


Figure I-19. Concentrations of Molybdenum in Leachates Generated from FBC Wastes and Disposal Media.

waste. The Exxon waste leachate from Step 1 was about an order of magnitude above the Alliance waste Step 1 leachate. And the Alliance results were an order of magnitude above the Georgetown waste. All of the Alliance field cells had molybdenum concentrations about an order of magnitude above the Exxon field cells.

Batch leaching of the disposal media resulted in molybdenum concentrations at or near the detection limits for all media. Most of the field control cells and lab control columns also had low concentrations, generally below 0.1 mg/L during the latter phases of the experiment. The exceptions were the lab control columns containing interburden (0.1 to 0.32 mg/L) and limestone (0.6 to 0.7 mg/L).

In general, batch leaching of the Exxon and Alliance wastes resulted in higher molybdenum concentrations than similar leaching of the disposal media. Lab leaching of the Georgetown waste resulted in leachates with molybdenum concentrations similar to the disposal media concentration. The Exxon field cell leachates had results very similar to comparable cells containing disposal media only. The Exxon lab leaching columns were higher than the field cells and the disposal media lab columns and field control cells. The Alliance field cells were consistently above both the Exxon and the disposal media-only field cells in molybdenum concentrations during the latter phases of the operational period.

I.5.16 Nickel

The concentration ranges for nickel are shown in Figure I-20. The mean and median concentration for the Step 1 Exxon PFBC waste leachates are quite far apart because the data consisted of two populations, one at the detection limit (0.02 mg/L) and one with a mean of 0.22 mg/L. Both the Step 2 and Step 3 leachates had nickel concentrations at or near the detection limit. During the latter phases of operation, the Exxon field cells had very consistent results, with nickel concentrations in the 0.014 mg/L (detection limit) to 0.038 mg/L range. The lab leaching columns produced similar results.

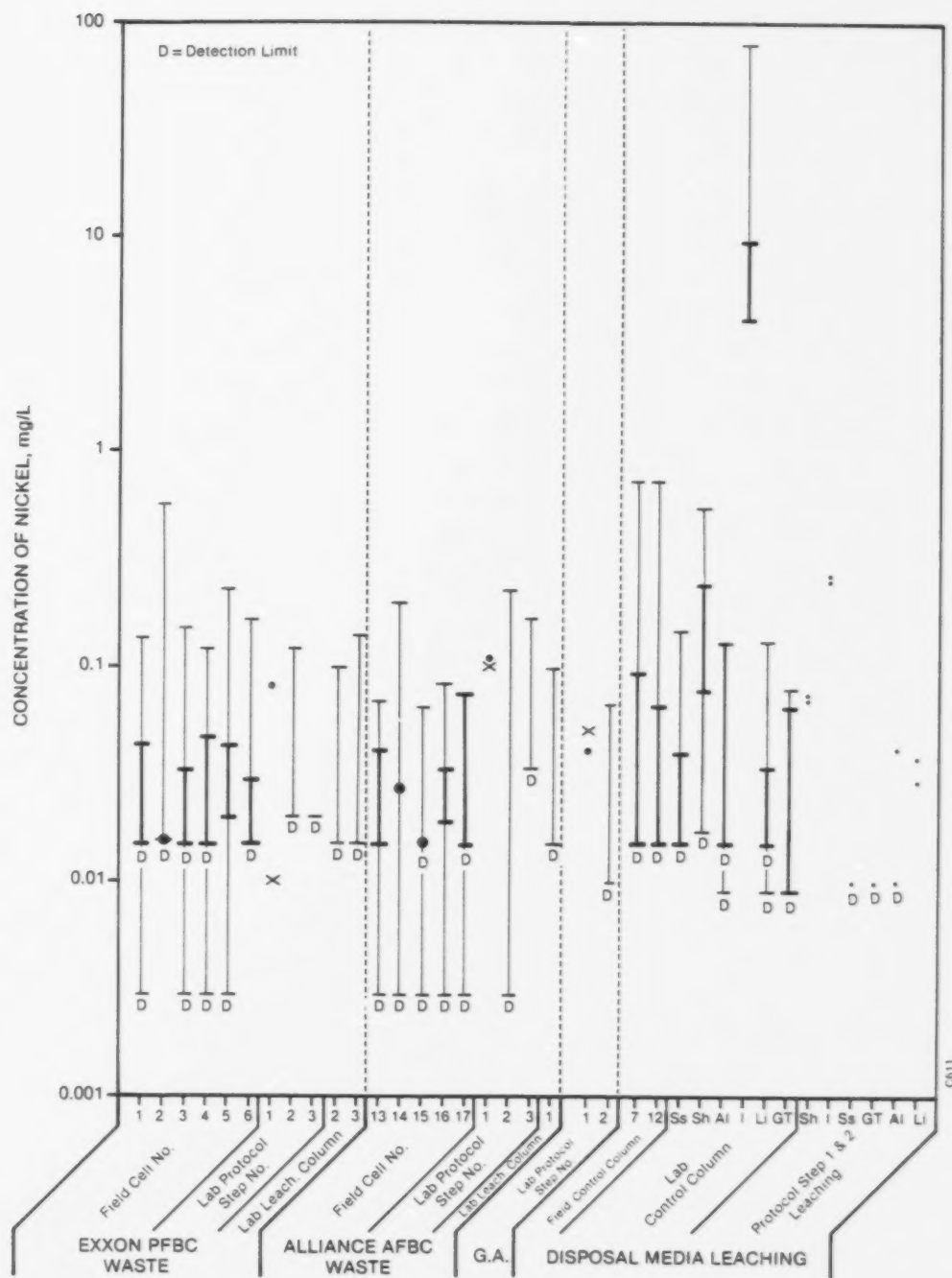


Figure I-20. Concentrations of Nickel in Leachates Generated from FBC Wastes and Disposal Media.

The Alliance AFBC waste, during Step 1 leaching, yielded leachates with a mean concentration of 0.11 mg/L. Step 2 repetition produced a broad range of concentrations spanning two orders of magnitude from 0.003 to 0.22 mg/L. Step 3 leaching yielded leachates with a range from 0.03 to 0.17 mg/L of nickel. The Alliance field cells had very consistent results, with an overall concentration range of 0.013 to 0.07 mg/L. The lab leaching column had similar concentrations.

For the Georgetown AFBC waste, the mean Step 1 concentration for nickel was 0.04 mg/L. Most of the Step 2 leachates were at or below the detection limit (0.01 mg/L), but the range extended up to 0.07 mg/L. In general, batch leaching of the Exxon and Alliance wastes yielded comparable nickel concentrations, and both had higher concentrations than the Georgetown waste. The field cell and lab leaching column results were much the same for the Exxon and Alliance wastes.

Batch leaching of the disposal media resulted in leachates with nickel values at or below the detection limit for the sandstone, glacial till, and alluvium. Limestone yielded concentrations of 0.03 to 0.036 mg/L. Interburden had the highest concentration, with about 0.25 mg/L. During the latter phases of operation, the field cells containing shale and alluvium and the lab control cells that contained sandstone, alluvium, limestone, and glacial till all had similar nickel concentration, from the detection limits (0.02 mg/L) to about 0.1 mg/L. The shale control column was slightly higher (0.07 to 0.22 mg/L), and the interburden was much higher, with a range from 3.8 to 9 mg/L.

Lab leaching of the disposal media and wastes yielded similar nickel concentrations. In general, the field control cells and lab control columns yielded nickel concentrations also in the same range as the waste-bearing field cells and lab leaching columns. The exception was the lab control column containing interburden, which had concentrations much higher than all other components of the study.

I.5.17 pH

The plots of the range of pH are shown in Figure I-21. The mean pH value in leachates from Step 1 leaching of the Exxon PFBC waste was about 12. Steps 2 and 3 yielded leachates with similar pH ranges, from 11 to 12.4. The lab leaching columns produced leachates with pH values also in the 11 to 12 range. The field cells, on the other hand, had pH's near neutrality, generally from 7 to 8 in the latter phases of operation. There was very little difference in the pH among the field cells.

The mean pH value in leachates from the Alliance AFBC waste was about 12.4. The pH range of leachates from both Steps 2 and 3 was from 12 to 13. The lab leaching column with Alliance waste also had a high pH, about 12. During the latter phases of operation, the Alliance field cells had much lower pH values, generally in the 7 to 8 range. The pH range of leachates from Step 2 and 3 leaching of the Georgetown waste was from 12.4 to 12.6.

Batch leaching of the disposal media produced leachates with pH's between 7.5 and 8.8 for shale, sandstone, glacial till, and limestone. For the interburden and alluvium leachates, the pH was between 5 and 6. Most of the field control cells and lab control columns yielded leachates near neutrality or slightly basic. The exceptions were the interburden, which had a pH of 2 during the latter phases of operation, and alluvium, which had a broad range of pH from 3.5 to 7.

Overall, the batch leaching of the wastes produced much higher pH's than similar leaching of the disposal media. During the latter phases of operation, the waste-bearing field cells had pH's comparable to the disposal media pH's (both field control cells and lab control columns) at or just above neutrality. The lab leaching columns produced leachates more comparable to the batch leaching results than to the field cell results.

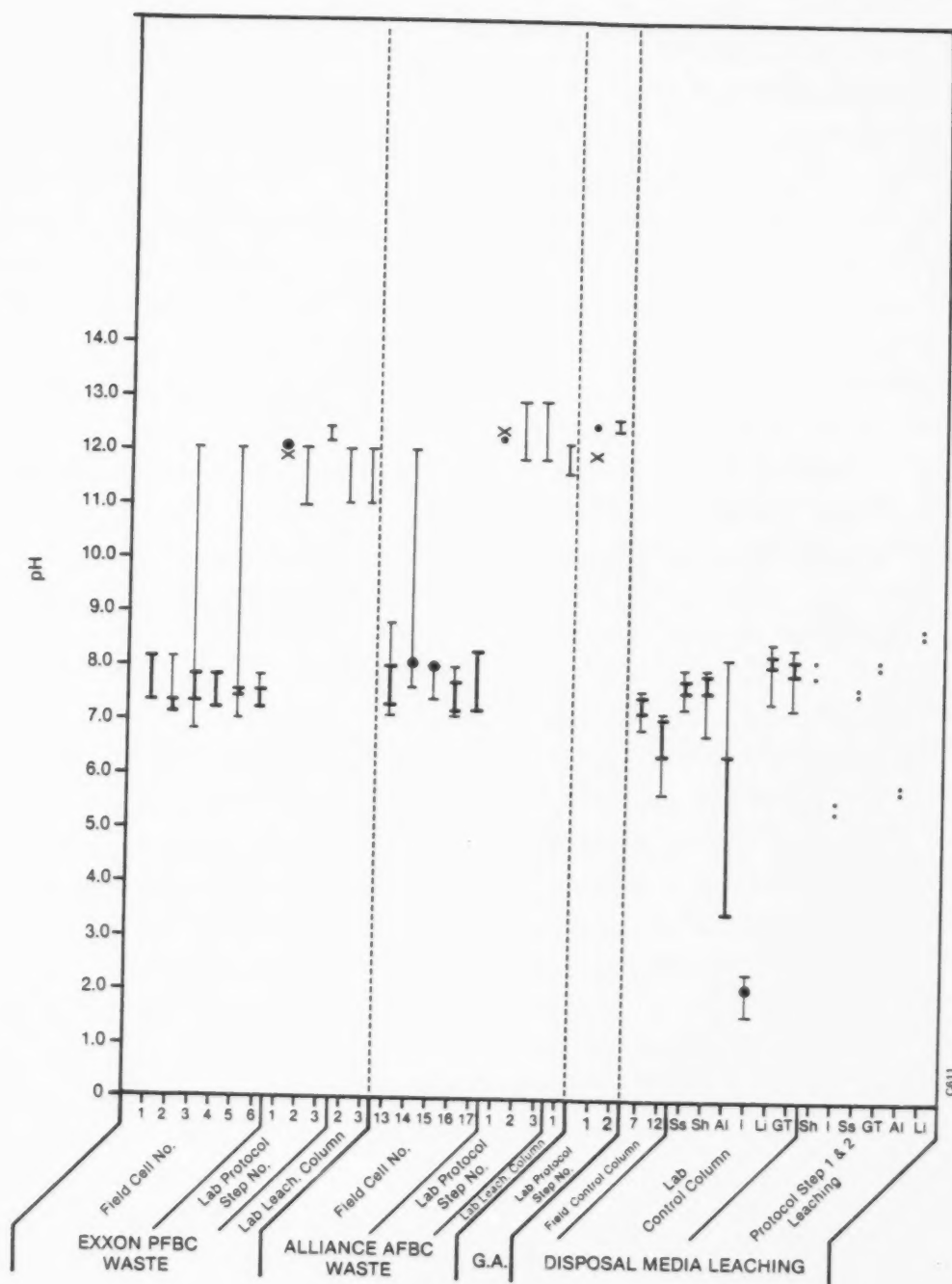


Figure I-21. Concentrations of pH in Leachates Generated from FBC Wastes and Disposal Media.

I.5.18 Potassium

Figure I-22 shows the concentration ranges for potassium. The mean and median Step 1 values for the Exxon PFBC waste are separated by more than an order of magnitude. Examination of the raw data base (Appendix J) shows that the reason for this was that many of the samples analyzed showed undetected potassium concentrations (<40 mg/L), whereas one set of four samples had concentrations ranging from 600 to 870 mg/L. All of the Step 2 and Step 3 leachates showed values below the 40 mg/L detection limit. The field cells had very similar overall ranges and generally more significant potassium concentrations. Cells 1, 3, 4, and 6 (containing shale, glacial till, limestone, and sandstone, respectively, in the upper layer) had very similar concentrations (110-240 mg/L) during the latter phases of operation. Cell 2, also containing shale, had slightly lower concentrations (50-100 mg/L), and Cell 5, containing alluvium, had higher concentrations (450-800 mg/L) during the latter phases of operation. The two lab leaching columns containing PFBC waste had concentration ranges comparable to the field cell ranges.

The mean Step 1 potassium concentration for the Alliance AFBC waste was 1.8 mg/L. The Step 2 repetitions resulted in a range of values from 8.2 to 36 mg/L. Step 3 repetitions had a relatively large range, from 70 to 320 mg/L. Leachates from the latter phases of field cell operation had somewhat variable concentrations among the cells from about 100 mg/L for Cell 17 (containing shale in the upper layer) to over 1000 mg/L for Cell 15 (containing alluvium). Both alluvium-bearing cells had higher potassium values than the other cells. The lab leaching column containing Alliance waste had an order-of-magnitude concentration range (70 to 900 mg/L) coinciding with the field cell ranges.

Batch leaching of the Georgetown AFBC waste yielded leachates with lower potassium concentrations than were found for the other two FBC wastes, with a mean of 17 mg/L for Step 1 and a range of 1 to 16 mg/L for Step 2.

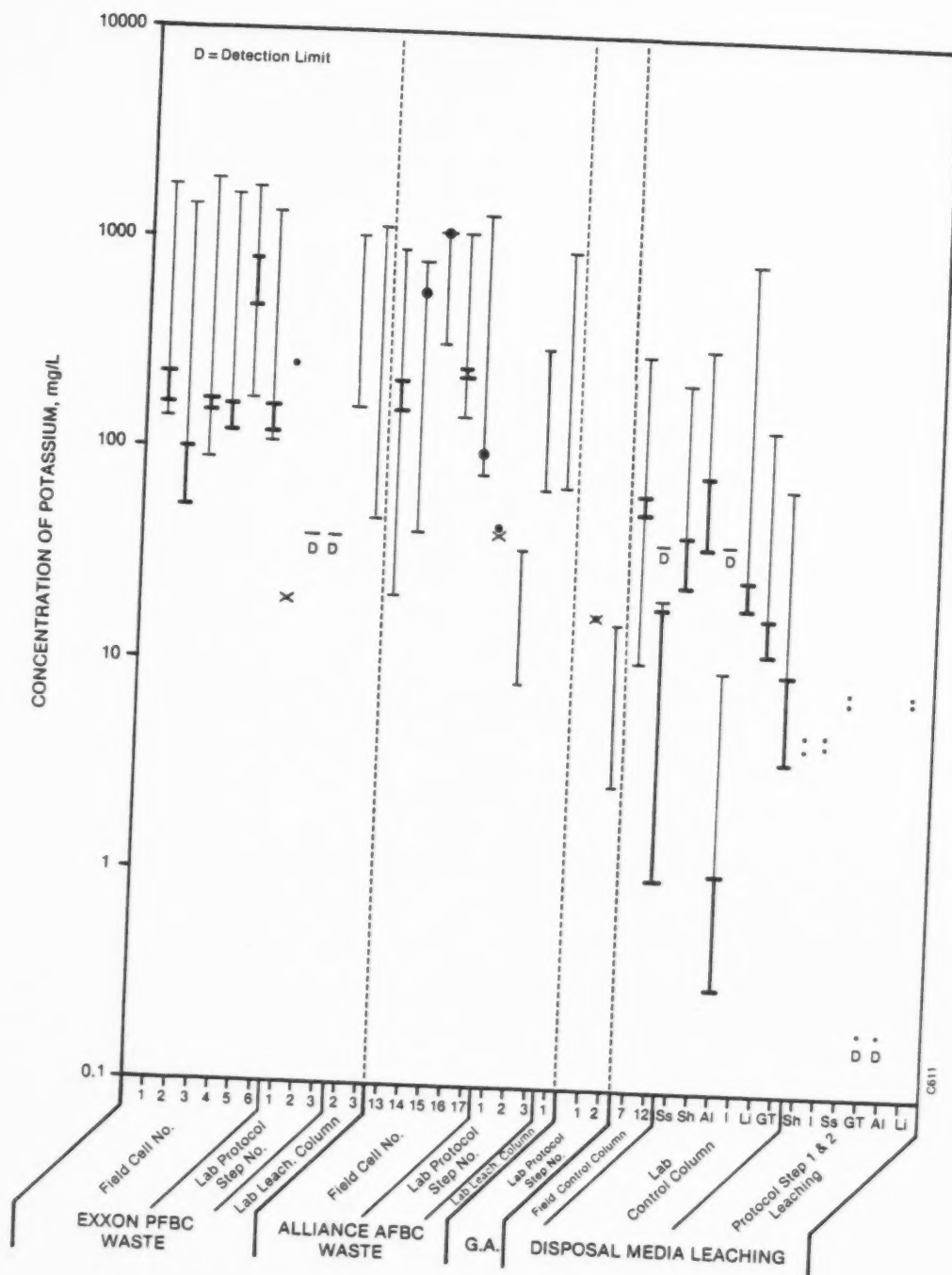


Figure I-22. Concentrations of Potassium in Leachates Generated from FBC Wastes and Disposal Media.

An unequivocal comparison of the batch leaching results for the three FBC wastes cannot be made because of the high detection limits for the Exxon PFBC waste. The ranges of concentration for the Step 1 and Step 2 leachates from the Georgetown AFBC wastes were generally lower than the parallel leachates from Alliance AFBC waste. The Exxon PFBC and Alliance AFBC field cell results were relatively similar in their potassium concentration ranges (generally 100 to 1000 mg/L).

Batch leaching of the disposal media resulted in two groups of potassium concentrations; the shale, interburden, sandstone, and limestone had concentrations of 4 to 9 mg/L, and the glacial till and alluvium had concentrations of 0.2 mg/L or less. The glacial till and alluvium lab control columns and field control cells, during the latter part of the operational period, were generally lower in concentration than for the other media. These concentrations were lower than 10 mg/L, except for the alluvium control columns, which ranged up to 20 mg/L. The other field cells and control columns had leachate concentrations in the 10 to 90 mg/L range during the latter phases of operation.

Overall, the leachates from the wastes had higher potassium concentrations than the leachates from the disposal media, at least in the lab column and field cell components of the program. The leachates from the waste-bearing field cells and lab columns generally had concentrations greater than 100 mg/L during the latter phases of operation; whereas the disposal media leachate concentrations were less than 100 mg/L. The batch leaching results were quite comparable for the waste and disposal media.

I.5.19 Silicon

Figure I-23 shows the concentration ranges for silicon. The mean concentration from Step 1 leaching of Exxon PFBC waste was 1.25 mg/L. Repetitions of Step 2 resulted in concentrations ranging from 0.5 to 3.1 mg/L. Step 3 repetitions produced leachates with lower concentrations, from 0.3 to

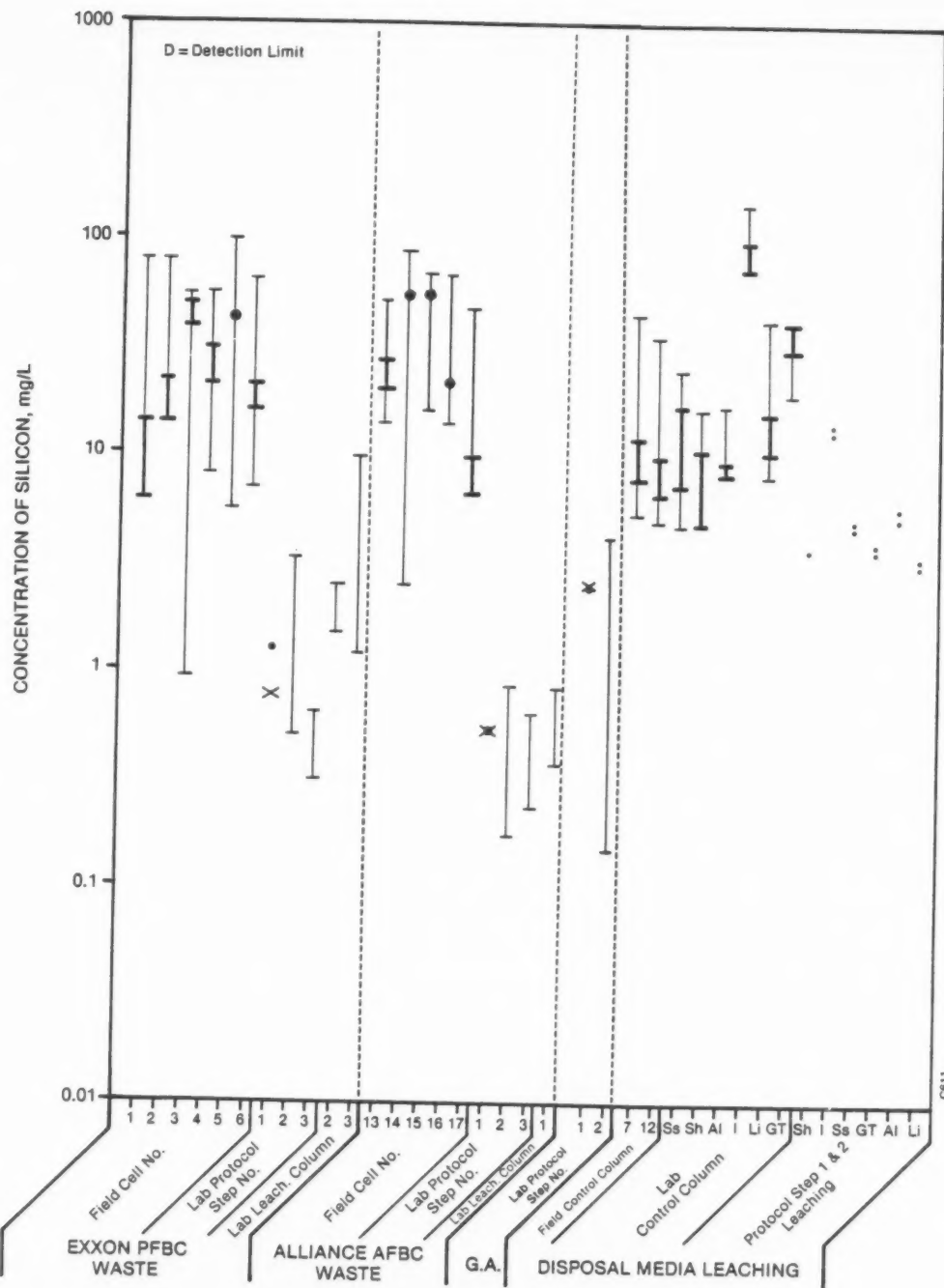


Figure I-23. Concentrations of Silicon in Leachates Generated from FBC Wastes and Disposal Media.

0.7 mg/L. The field cells containing PFBC waste had higher silicon concentrations. During the latter part of the period of operation, the concentrations ranged from 6 to 50 mg/L. Cell 1, one of the shale-bearing cells, had the lowest concentration range, whereas Cell 3, containing glacial till, had the highest range during the latter stages of operation. The lab leaching columns yielded leachate with silicon in the 1 to 10 mg/L range, which is typical for most ground water.

The mean Step 1 concentration for Alliance AFBC waste leachate was 0.55 mg/L. Step 2 and Step 3 repetitions yielded leachates with similar concentration ranges, from 0.15 to 0.9 mg/L of silicon. The field cell leachates again had higher leachate concentrations; Cell 17, which contained shale, had the lowest range (7-10 mg/L) during the latter stages of operation. Cells 14 and 15, containing alluvium, produced leachates with the highest concentrations (55 mg/L). The lab leaching column with Alliance waste had a lower concentration range that was comparable to the batch leaching results (0.35-0.8 mg/L).

The mean Step 1 leachate concentration for the Georgetown AFBC waste was about 2.4 mg/L. Step 2 repetitions resulted in a very broad concentration range from 0.01 to 40 mg/L of silicon. The batch leaching results were similar for the Georgetown and Exxon wastes, but the Alliance waste had lower batch leachate concentrations. For both the Exxon and Alliance wastes, the silicon values were substantially lower for the batch studies than for the field cells. The field cell results were very similar for the Exxon and Alliance wastes.

Batch leaching of the disposal media resulted in leachates with silicon concentrations in the 3 to 14 mg/L range. The field cell and lab column results were very similar to each other and were overall higher than the batch leaching results. Six of the eight cells and columns had an overall concentration range of 5 to 15 mg/L. The till-bearing column had a 30 to 40 mg/L range, and the interburden column had a range of 70 to 100 mg/L.

The batch leaching of the disposal media yielded silicon concentrations consistent with the results from leaching of the Georgetown and Exxon waste but higher than the Alliance batch leaching results. The lab columns and field cells containing disposal media only yielded leachates with generally very slightly lower silicon concentrations than the field cells containing waste. The lab leaching column leachates were lower in silicon concentration and were more comparable to the batch leaching results than to the other lab column and the field cell results.

I.5.20 Sodium

The concentration ranges for sodium are shown in Figure I-24. The mean concentrations for leachate from Step 1 leaching of Exxon PFBC waste was about 17 mg/L. Step 2 repetitions yielded leachates with comparable sodium concentrations. The Step 3 leachates were generally higher in sodium concentration. The PFBC field cells produced leachate with higher sodium concentrations than were found in the Step 1 and Step 2 extractions. The overall concentration ranges were quite comparable for all the field cells except that Cell 2, one of the cells with shale in the upper layer had a larger range than the other cells. The record from the latter part of the operational period showed somewhat more distinction among the cells; the alluvium-bearing cell (Cell 5) produced higher sodium values (>150 mg/L) than the others, and one of the shale-bearing cells (Cell 2) yielded lower concentrations of sodium (≤ 40 mg/L). The lab leaching columns had sodium concentration ranges comparable to the field cells, although the minimum values were higher than in the field cells.

Step 1 leaching of Alliance AFBC waste resulted in a leachate with a sodium concentration of about 13 mg/L. Step 2 produced leachates with lower concentrations (<10 mg/L), and Step 3 produced leachates with higher concentrations (20 to 90 mg/L). The Alliance field cells generally produced higher concentrations of sodium than Step 1 and Step 2 leaching. The alluvium-bearing cells produced somewhat higher concentrations than the other cells. The lab leaching column leachate results were comparable to the field cell results.

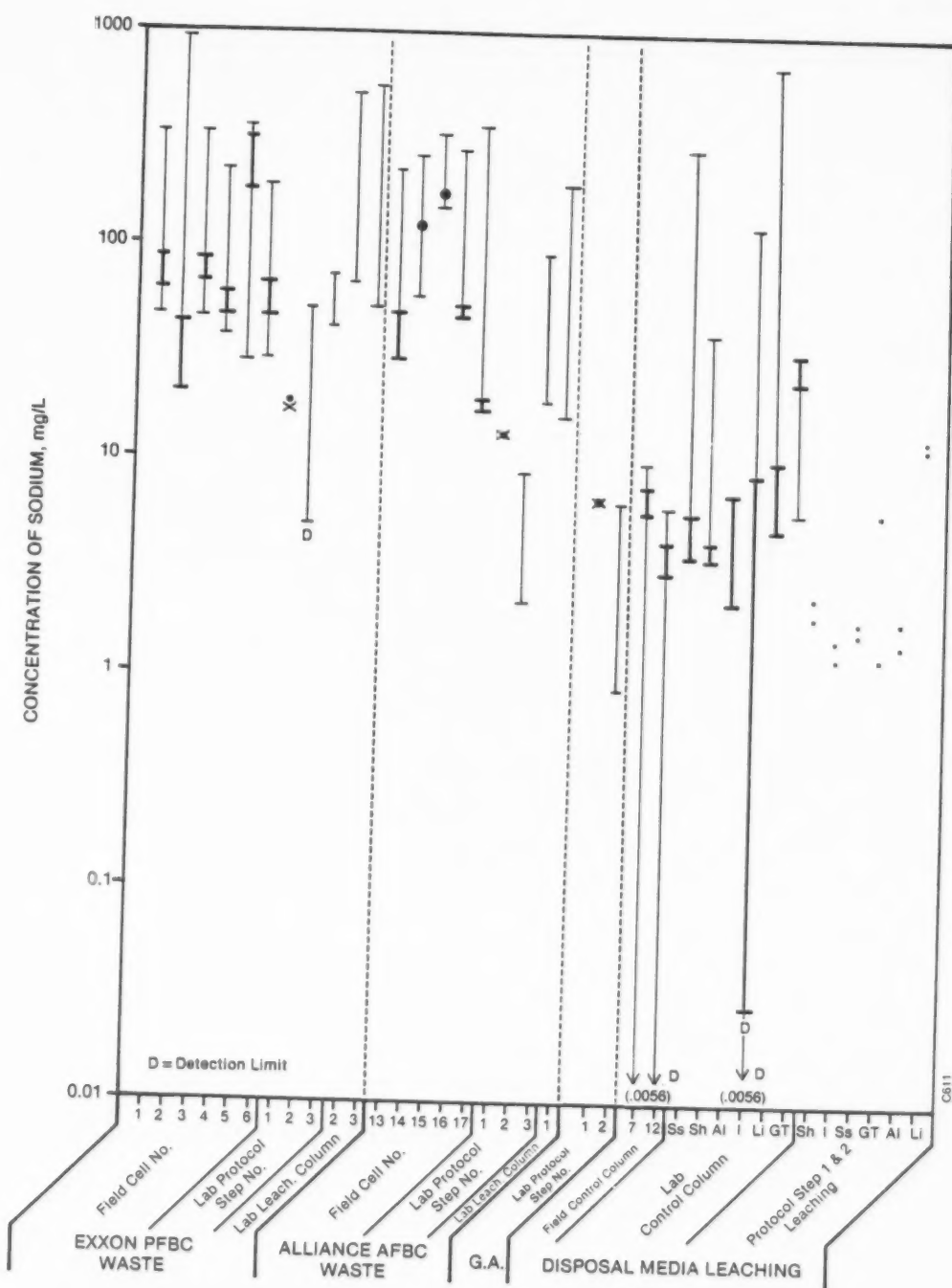


Figure I-24. Concentrations of Sodium in Leachates Generated from FBC Wastes and Disposal Media.

Step 1 leaching of the Georgetown AFBC waste resulted in a mean sodium concentration of 6.5 mg/L. The Step 2 range was from 1 to 10 mg/L. In general, the lab batch leaching of the three FBC wastes tested had quite consistent results; Step 1 leachates were in the 5 to 20 mg/L range, and the Step 2 leachates were often below the Step 1 leachate in sodium concentration. The field cells, during the latter stages of operation, produced leachates in the 10 to 100 mg/L range (except the alluvium-bearing cells, which produced leachates with >100 mg/L of sodium).

Batch leaching of the disposal media yielded leachates in the 1 to 13 mg/L range, and most were in the 1 to 3 mg/L range. The lab control columns and field control cells produced leachates with very wide concentration ranges spanning five orders of magnitude. When the latter part of the operation is viewed, though, a more clear and consistent pattern emerges. Most of these latter leachates were in the 2 to 10 mg/L range. Glacial till had a higher range of concentration (20 to 35 mg/L) than the other. Interburden yielded leachates spanning about 3 orders of magnitude in concentration range.

For sodium, the leachates from the wastes generally had higher concentrations than the leachates from the disposal media, particularly when the latter part of the period of field cell and lab column operation is viewed. Batch leaching of the disposal media yielded leachates only slightly lower in sodium concentrations than similar leaching of the wastes. The field cells and lab columns containing wastes produced sodium concentrations about an order of magnitude higher than the cells and columns containing only disposal media.

I.5.21 Strontium

The concentration range plots for strontium are shown in Figure I-25. For Exxon PFBC waste, the Step 1 mean concentration was about 2.8 mg/L. The range for the Step 2 repetition was somewhat lower (0.3 to about 2.5 mg/L), and the range for the Step 3 repetitions was somewhat higher (4 to 5 mg/L). The PFBC field cells had generally lower strontium concentration ranges than

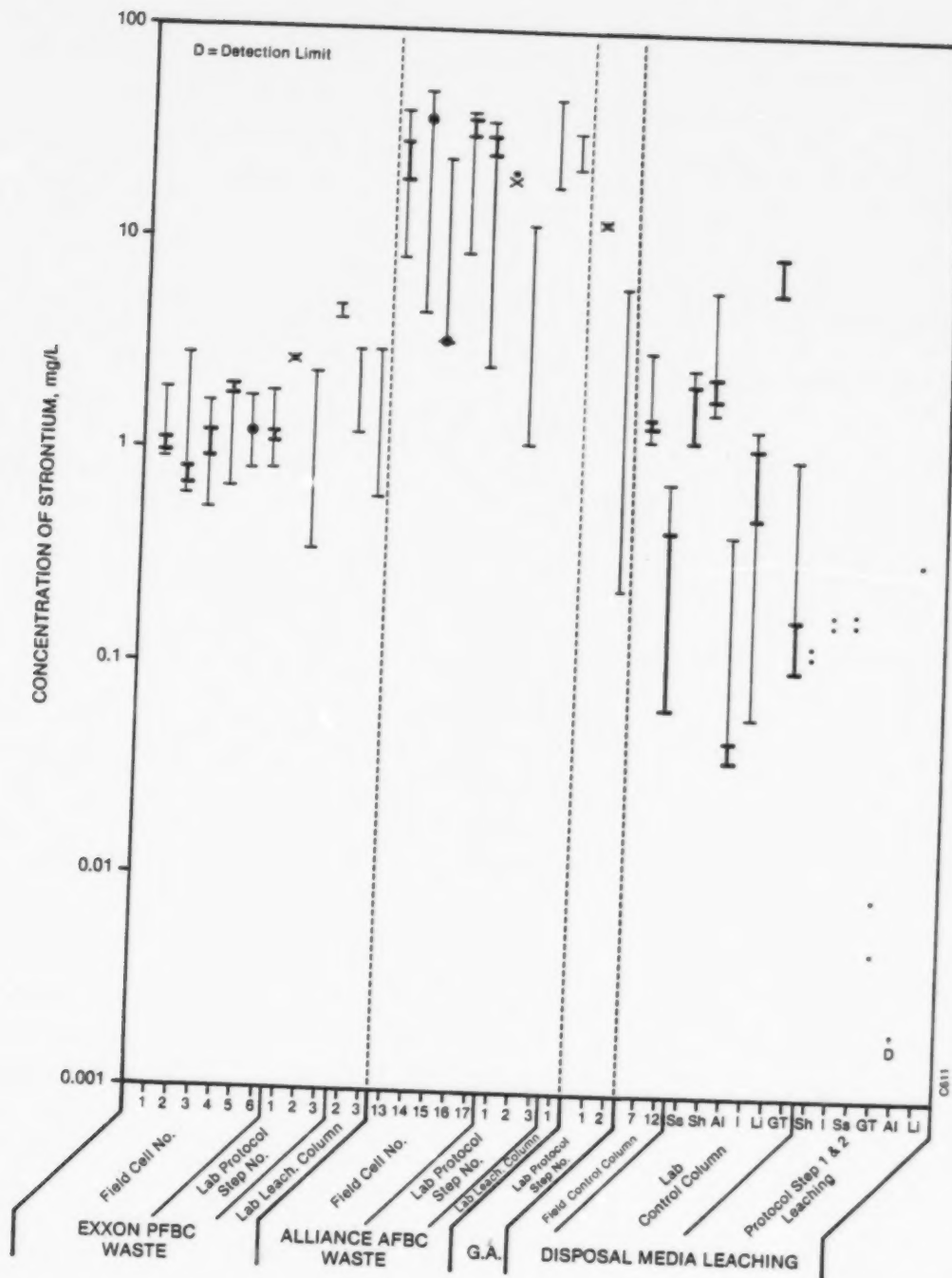


Figure I-25. Concentrations of Strontium in Leachates Generated from FBC Wastes and Disposal Media.

the Step 1 leachate, particularly when the latter part of the period of operations is considered. This part of the record showed from 0.7 to 2.0 mg/L for all cells; the ranges were very narrow and were consistent for all the cells. One of the shale cells was slightly lower than the other cells, and the limestone cell was somewhat higher. The lab leaching columns showed strontium concentrations consistent with the lab and field cell results.

The mean Step 1 strontium concentrations for the Alliance AFBC waste was about 20 mg/L. Repetitions of both Step 1 produced leachates that were lower in concentration (1 to 10 mg/L), but Step 3 repetitions resulted in a higher concentration range. The results from the Alliance AFBC field cells were generally consistent and showed somewhat higher concentrations than the Step 1 and 2 leaching, with the exception of one of the alluvium-bearing cells, which had lower concentration values. When the latter part of the record is considered, the concentrations were 20 to 40 mg/L, except for the alluvium-bearing cell noted above, which showed a concentration of 6 to 7 mg/L. The strontium concentrations in the leachates from the lab leaching column were similar to the batch leaching and field cell concentrations.

Step 1 leaching of the Georgetown AFBC waste resulted in a mean strontium concentration of 1.3 mg/L. The range of values for Step 2 repetitions was from 0.24 mg/L to 6.3 mg/L.

Batch leaching of the disposal media resulted in strontium values that fell into two groups -- the glacial till and alluvium had low values (<0.01 mg/L) and the other media had higher values (0.1 to 0.4 mg/L). Considering the latter part of the operational period, alluvium yielded lower strontium values (<0.5 mg/L) than the other media in both the field control and the lab control columns. Glacial till also had low concentrations (<0.2 mg/L) during the latter part of the performance period. Limestone had higher values (5 to 9 mg/L) than the other media in the lab control columns.

In general, the concentration ranges for the Alliance AFBC wastes were higher than for the disposal media, with the exception that the Step 2 batch leaching yielded concentrations about the same as the concentrations in

shale, sandstone, and limestone leachates. The Exxon PFBC waste yielded leachates that were comparable to the shale, sandstone, interburden, and limestone leachates but that were higher in strontium concentrations than the alluvium and glacial till leachates. Batch leaching of the waste over-all yielded higher concentrations than similar leaching of the disposal media.

I.5.22 Sulfate

Figure I-26 shows the concentration ranges for sulfate. For Exxon PFBC waste, the mean concentration in leachate from Step 1 of the lab protocol was about 1200 mg/L. Repetitions of both Step 2 and Step 3 resulted in concentration ranges between 1000 and 1500 mg/L. The overall concentration ranges for the field cells were in the 1000-9000 mg/L range, except the cell containing sandstone, which ranged down to about 350 mg/L. The concentration ranges from the latter part of the period of operation were much more restricted and were quite close for all the field cells in the 1000 to 2500 mg/L range. The two lab leaching columns had comparable sulfate concentration ranges, with values in the 1000 to 3000 mg/L range.

The mean sulfate concentration in leachates from Step 1 leaching of the Alliance AFBC waste was about 1100 mg/L. Step 2 and Step 3 repetitions yielded leachates with limited concentration ranges in the 1000 to 1200 mg/L range. The field cells containing Alliance waste had a concentration range generally from 1000 to 5000 mg/L, except for the cell containing limestone, which ranged down to about 350 mg/L. Leachates from the latter part of the period of operation had more restrictive ranges in the 900 to 1500 mg/L range. The lab leaching column had a comparable concentration range.

Step 1 leachates from the Georgetown AFBC waste had a mean concentration of 1400 mg/L. The Step 2 leachates ranged down to <10 mg/L. All three FBC wastes yielded leachates with remarkably similar sulfate concentrations from parallel components of the study. The lab protocol leaching of the wastes resulted in sulfate concentrations which were nearly the same for all three wastes (except for the very low concentration observed in Step 2

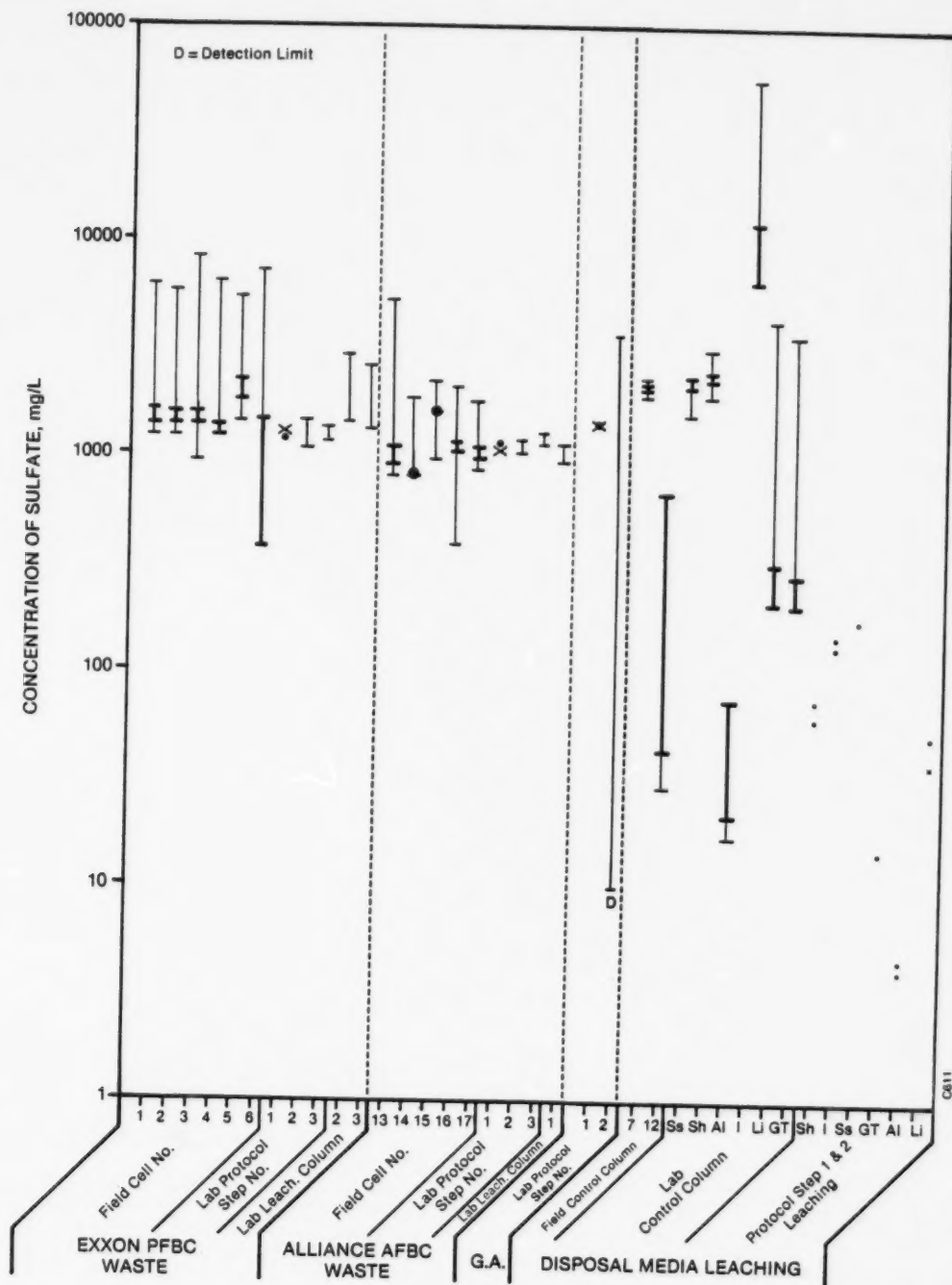


Figure I-26. Concentrations of Sulfate in Leachates Generated from FBC Wastes and Disposal Media.

leachates from the Georgetown waste). The field cell leachates had very slightly lower sulfate concentrations for the Alliance cells than for the Exxon cells. The lab leaching results were also higher for the Exxon columns than for the Alliance column.

Leaching of the disposal media yielded less consistent results. Lab protocol leaching of the media resulted in low sulfate concentrations (<10 mg/L) for alluvium. The concentrations for the interburden and sandstone were in the 100 to 200 mg/L range. The concentrations for the shale glacial till and limestone were in the 15 to 75 mg/L range. In the lab columns and field cells, alluvium leachate had lower sulfate concentrations than the other media. Interburden leachates had the highest sulfate values of all the solids studied, including both wastes and disposal media, which is not surprising considering that this column is performing essentially as an acid mine drainage system. The sandstone field control cell and lab control column yielded leachates with virtually identical sulfate concentration.

Comparison of the results of lab column leaching of the wastes with lab column leaching of the disposal media shows that the waste leachates were comparable to leachates from the sandstone and shale and were lower in sulfate concentrations than leachates from the interburden. The waste leachates were generally lower in sulfate than the leachates from alluvium, limestone, and glacial till. Lab protocol leaching of the wastes results in much higher sulfate concentrations than similar leaching of disposal media.

I.5.23 Titanium

The concentration ranges for titanium are shown in Figure I-27. The mean Step 1 leachate concentration for the Exxon PFBC waste was less than the detection limit (0.002 mg/L) for eight of the twelve samples analyzed. The remaining four samples had a mean concentration of 0.15 mg/L. Step 2 and Step 3 leaching produced undetectable concentrations of titanium. The overall concentration range of titanium in the leachates from the field cells was quite large, from detection limit values (0.002 or 0.025 mg/L) to about 0.8 mg/L. During the latter phases of operation, the field cell

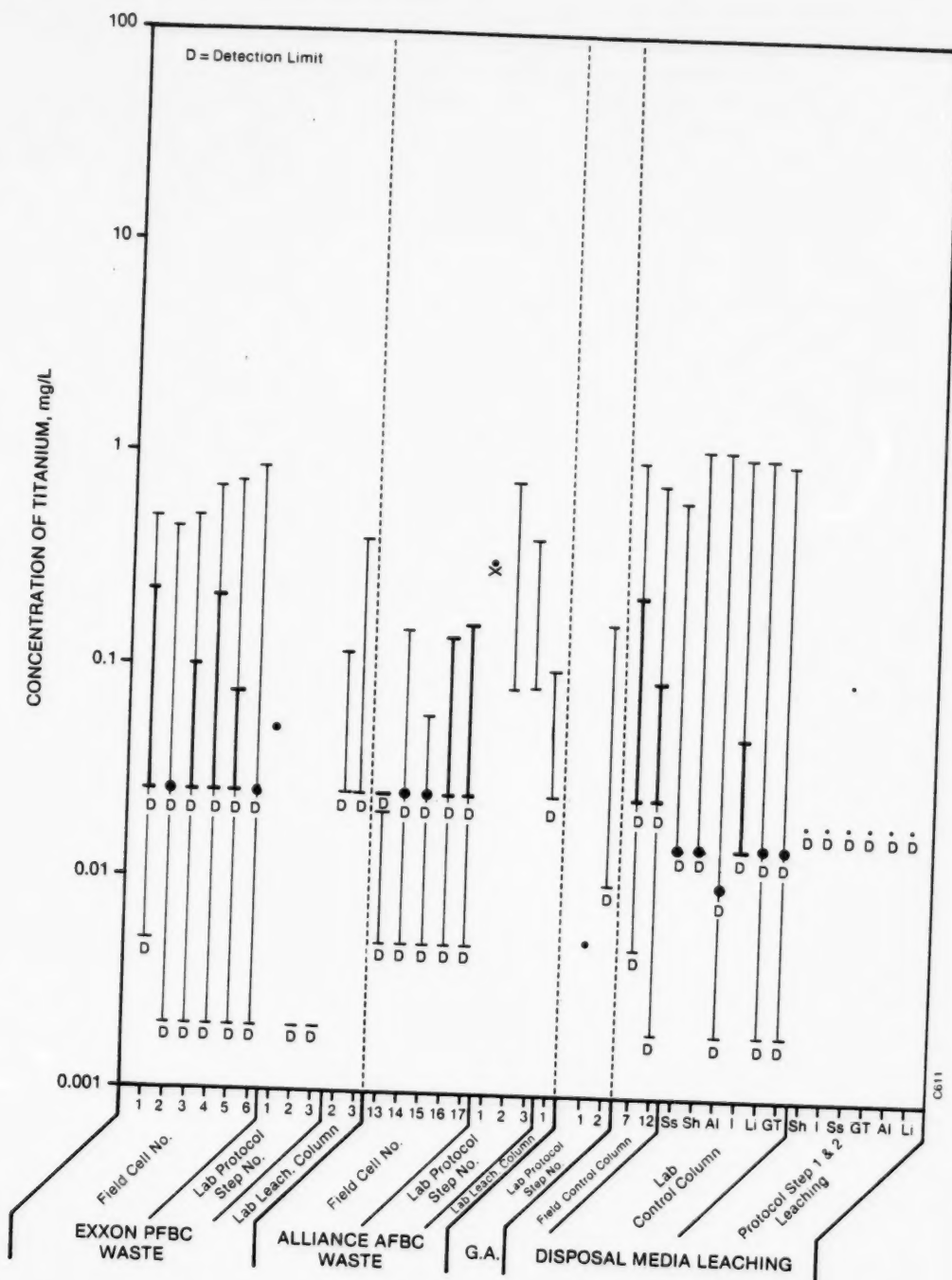


Figure I-27. Concentrations of Titanium in Leachates Generated from FBC Wastes and Disposal Media.

leachates ranged from the detection limit (0.25 mg/L) to 0.2 mg/L. The lab leachates had comparable concentrations to the field cell leachates.

Step 1 leaching of the Alliance AFBC waste resulted in a mean titanium concentration of about 0.3 mg/L. The range for Step 2 and 3 leaching was from 0.08 to 0.7 mg/L. The field cells yielded generally lower titanium concentrations, with an overall range of 0.025 to 0.15 mg/L during the latter phases of operation. The lab leaching column with Alliance AFBC waste yielded titanium concentrations comparable to the field cells.

The mean titanium concentration in Step 1 leachates from the Georgetown waste was 0.055 mg/L. Step 2 leaching resulted in a range of concentrations from the detection limit value (0.02 mg/L) to 0.17 mg/L.

Batch leaching of the disposal media yielded leachates generally with undetectable concentrations of titanium. Leachates from the field control columns ranged from the 0.025 mg/L detection limit to about 0.2 mg/L. All the lab control columns except interburden had leachates with undetectable titanium concentrations during the latter phases of operation. The interburden column had a range from the 0.025 mg/L detection limit to 0.4 mg/L.

I.5.24 Total Dissolved Solids

Figure I-28 shows the concentration range plots for TDS. The mean Step 1 leachate concentration value for Exxon PFBC waste was about 3200 mg/L. Step 2 repetitions yielded leachates with somewhat lower concentrations of about 2000 to 2700 mg/L. Step 3 repetitions produced leachates in the 3000 to 3500 mg/L range. Leachates from the PFBC field cells had remarkably similar TDS concentrations in the 2000 to 3500 mg/L range during the latter phases of operation. The alluvium-bearing cell (Cell 5) yielded slightly higher concentrations than the other cells. The lab leaching columns containing Exxon waste had concentration ranges similar to those observed for the field cells, about 2000 to 5000 mg/L.

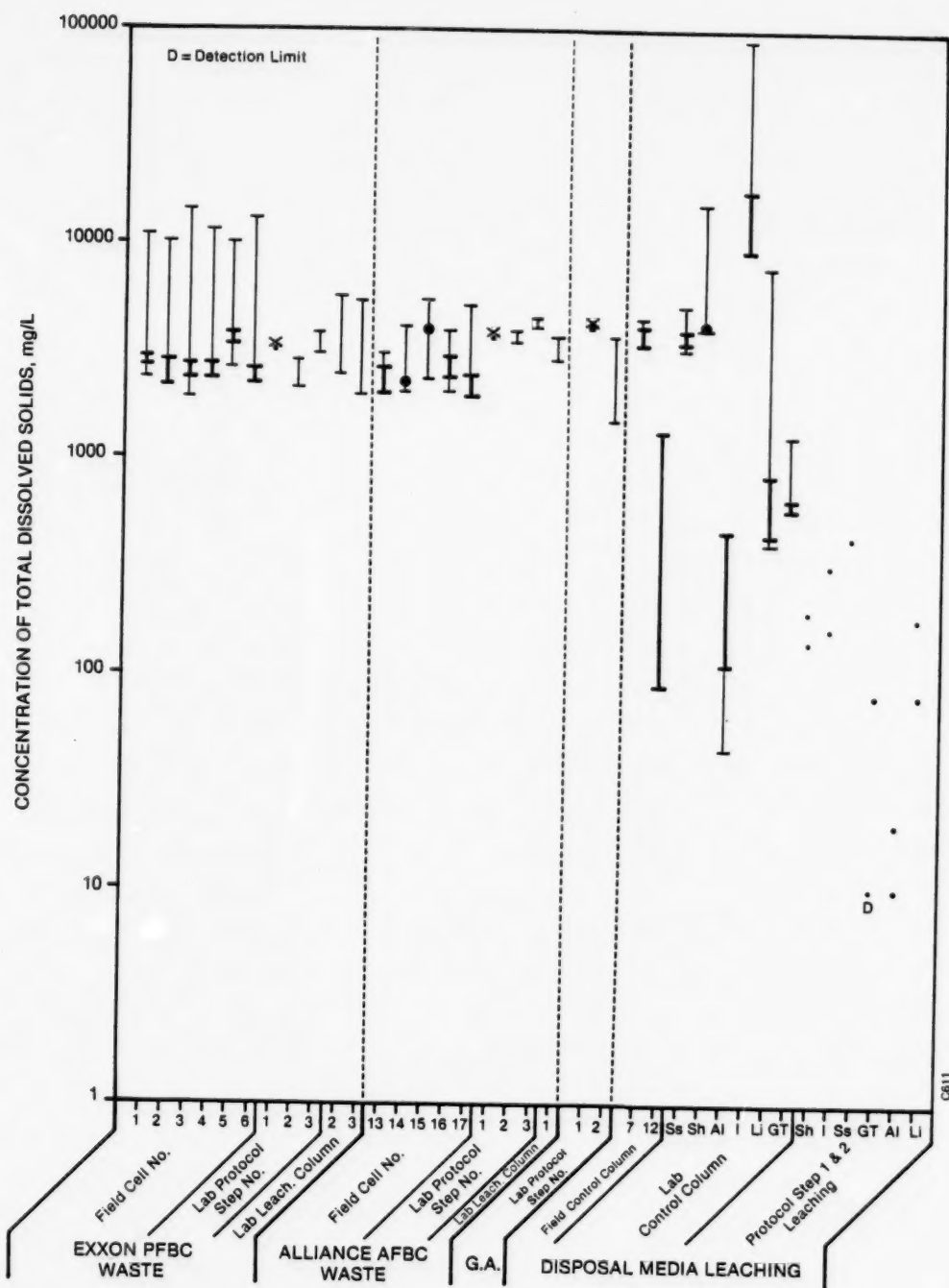


Figure I-28. Concentrations of Total Dissolved Solids in Leachates Generated from FBC Wastes and Disposal Media.

The mean Step 1 leachate concentration for the Alliance AFBC waste was about 3400 mg/L of TDS. Step 2 leachates had a narrow concentration range around the same value. Step 3 repetition yielded leachates also with a narrow concentration range, but with slightly higher values. During the latter phases of operation, the Alliance field cells produced leachates with a relatively narrow concentration range overall in the 2000 to 4000 mg/L range. Cell 15, one of the alluvium-bearing cells, had the highest concentrations of TDS. The Alliance AFBC lab leaching column had a generally higher range of concentrations than the field cells, from 2700 mg/L to 3200 mg/L.

Step 1 leaching of the Georgetown AFBC waste resulted in a mean TDS concentration of about 4000 mg/L. Step 2 repetitive leaching of the waste yielded lower concentrations in the 1500 to 3800 mg/L range. In general, the three FBC wastes yielded leachates with remarkably similar TDS concentrations for all phases of the program. The alluvium-bearing field cells possibly showed a tendency toward higher TDS values than the other cells.

Leaching of the disposal media produced less consistent results. Batch leaching of the media produced two distinct sets of results; leaching of the alluvium and glacial till produced low TDS concentration (10 to 80 mg/L), whereas leaching of the shale, interburden, and sandstone yielded leachates with TDS concentrations in the 140 to 400 mg/L range. The limestone leaching results had one value in the lower and one in the higher range. The lab control columns and field cells similarly had divergent results. The alluvium-bearing field cell and control column had the lowest concentration ranges during the latter phases of operation (90 to 450 mg/L). The interburden control column had the highest TDS concentrations, with values in the 9000 to 18000 mg/L range. The other cells and columns had leachates with intermediate concentrations. The shale and sandstone cells and columns had similar concentrations in the 3000 to 4000 mg/L range.

Batch leaching of the disposal media resulted in TDS concentrations at least an order of magnitude lower than the concentrations observed from similar leaching of the wastes. The lab leaching columns and field cells that

contained wastes produced leachates that were very similar in TDS concentration and were comparable to the shale and sandstone lab control column and field cell results. The waste-bearing field cells and leaching columns had lower TDS concentrations than the interburden control column and higher concentrations than the alluvium, limestone, and glacial till field cells and control columns. The alluvium-bearing cells showed inconsistent results between the cells and columns containing waste (where the alluvium cells had the highest TDS values) and the cells and columns containing no waste (where the alluvium cells showed the lower TDS values).

I.5.25 Vanadium

The concentration ranges for vanadium are shown in Figure I-29. Eight of the 12 Step 1 leachates from Exxon PFBC waste had undetectable vanadium concentrations (<0.02 mg/L). The remaining four leachates had a mean concentration of 0.25 mg/L. Step 2 and 3 repetitions produced leachates with undetectable concentrations of vanadium. During the latter phases of operation, the Exxon field cells produced leachates with very consistent concentrations over an order of magnitude (0.013 to 0.14 mg/L). The lab leaching columns had similar concentration ranges.

The Alliance AFBC waste produced leachates during Step 1 leaching with a mean vanadium concentration of 0.26 mg/L. Repetition of Step 2 and 3 resulted in concentrations ranging from 0.08 to 0.6 mg/L. The Alliance field cells again were quite consistent, with an overall concentration range spanning an order of magnitude, from 0.013 to 0.21 mg/L. The lab leaching column also again had a similar concentration range to the field cells.

The Georgetown AFBC waste, when subjected to Step 1 leaching, yielded four leachates with detection limit values (0.01 mg/L). The mean concentration of the other two leachates was 0.06 mg/L. Step 2 leaching resulted in a concentration range from the detection limit (0.01 mg/L) to 0.15 mg/L.

The disposal media, when subjected to batch leaching, produced leachates with generally undetectable vanadium concentrations. The lab control

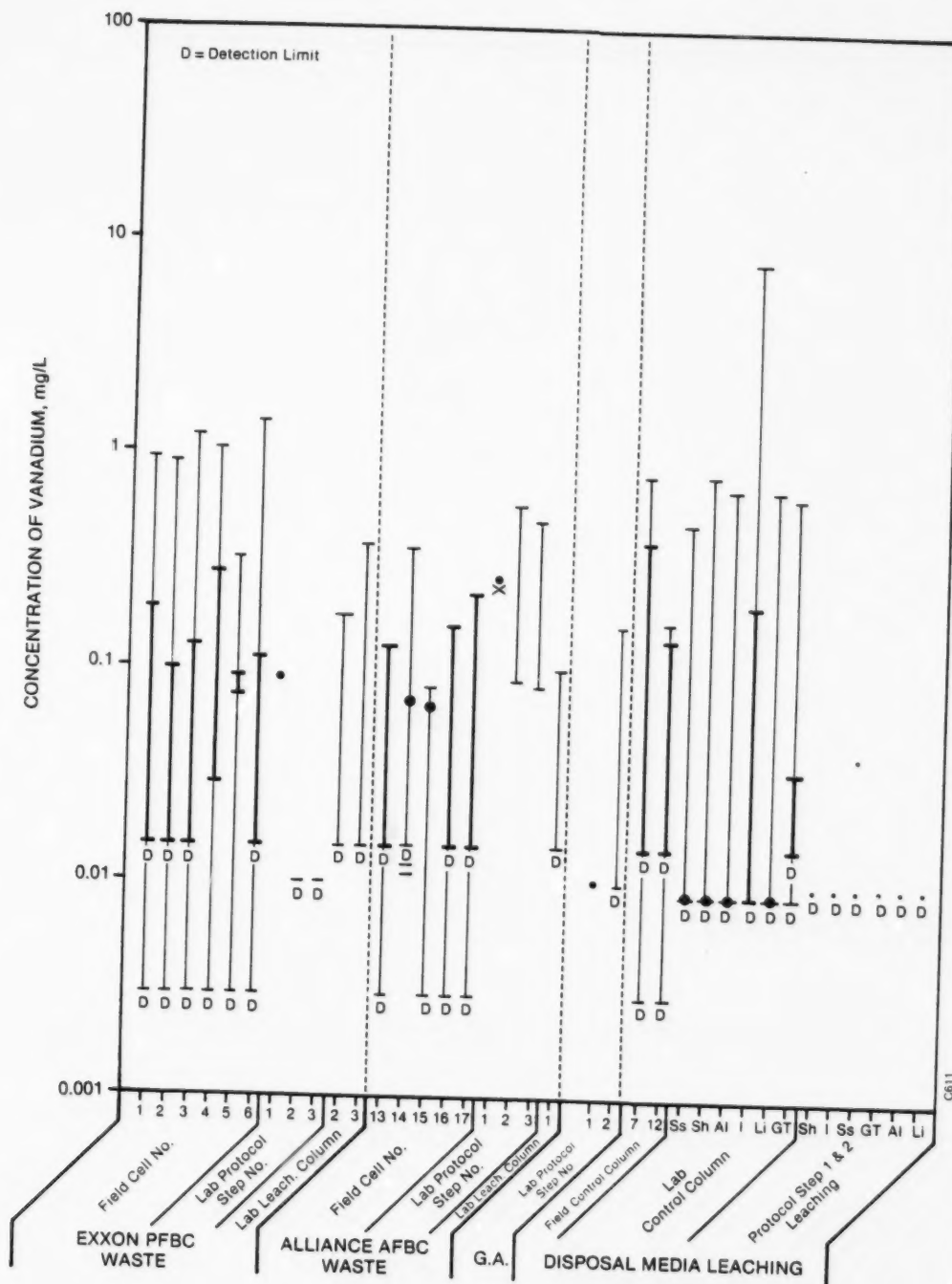


Figure I-29. Concentrations of Vanadium in Leachates Generated from FBC Wastes and Disposal Media.

column values were at the detection limit for four of the columns. The interburden column ranged up to about 0.2 mg/L, and the till column reached about 0.015 mg/L. During the latter phases of operation, the field control columns had a relatively large range of vanadium concentrations, from 0.013 to 0.4 mg/L. Overall, the results from the field control cells and the field cells with waste had very similar results. Batch leaching of the wastes, particularly the Alliance waste, yielded higher vanadium concentrations than similar leaching of the disposal media.

I.5.26 Zinc

The concentration ranges for zinc are plotted in Figure I-30. The Step 1 leachate from Exxon PFBC waste had a mean zinc concentration of 0.13 mg/L. The Step 2 leachates had a broad concentration range from 0.002 to 0.3 mg/L. The range for the Step 3 leachates was much narrower, from 0.11 to 0.2 mg/L. The field cells behaved rather consistently, with leachate concentrations ranging from detection limit values (0.013 mg/L) to as high as 0.38 mg/L during the latter phases of operation. Cell 5, containing alluvium, did not range as high as the other cells. The concentration ranges for the lab leaching column leachates were comparable to the field cell ranges.

The mean Step 1 leachate concentration for the Alliance AFBC waste was 0.04 mg/L. The Step 2 repetitions again yielded leachates with a broad concentration range, from the detection limit of 0.003 mg/L to 0.09 mg/L. The Step 3 leachates had a narrower concentration range, from 0.03 to 0.07 mg/L. During the latter phases of operation, the Alliance field cells yielded leachates with similar concentration ranges, from 0.015 to 0.04 mg/L. The lab leaching column containing Alliance waste ranged over a higher span of values, from 0.06 to 0.2 mg/L.

Step 1 leaching of Georgetown AFBC waste yielded leachates with undetectable zinc concentrations. Step 2 repetition resulted in a range of concentrations from detection limit values (0.01 mg/L) to 0.03 mg/L.

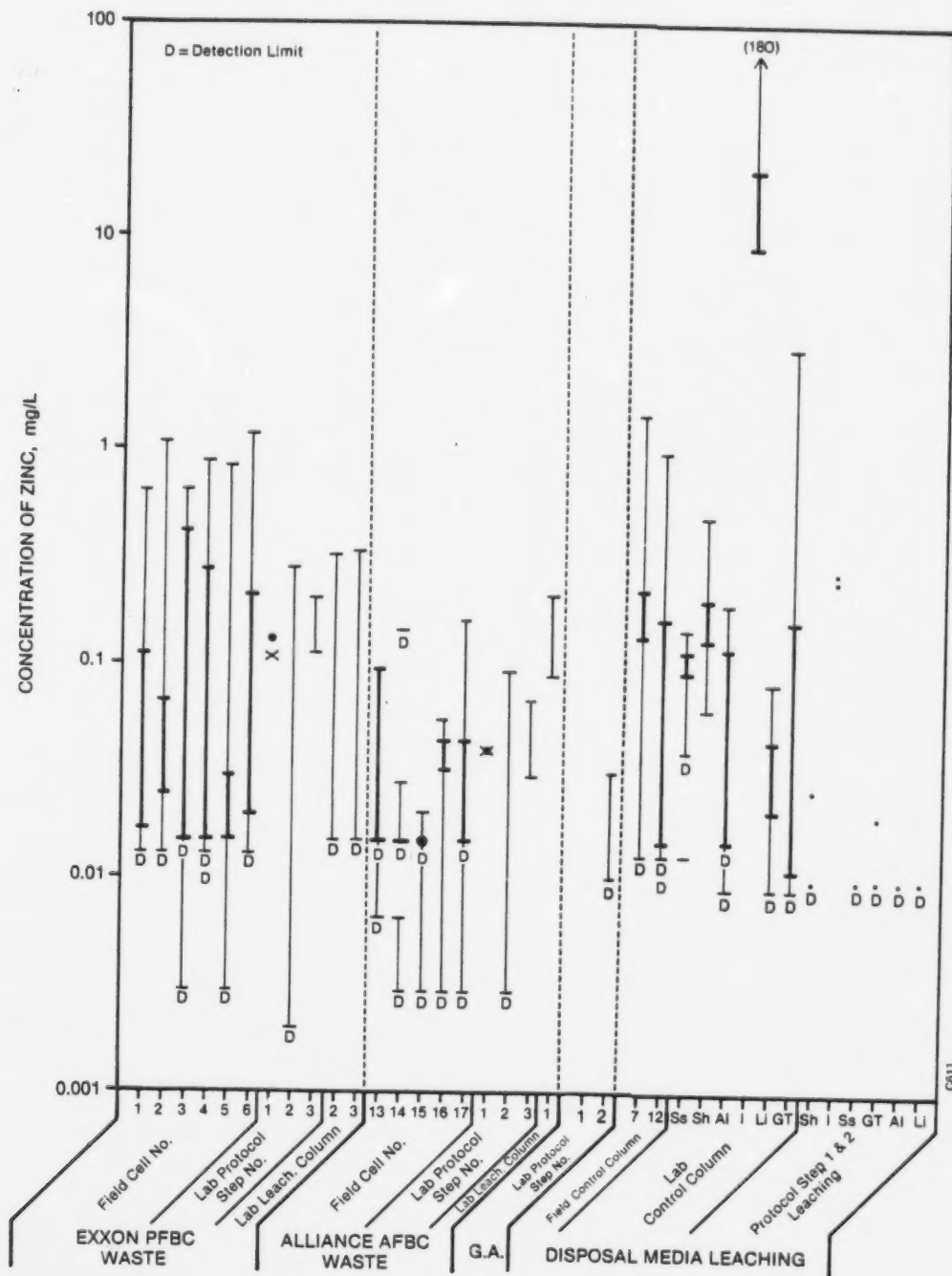


Figure I-30. Concentrations of Zinc in Leachates Generated from FBC Wastes and Disposal Media.

Most of the disposal media, during Step 1 leaching, had undetectable zinc concentrations or just above. The exception was interburden, which had a concentration of 0.25 mg/L. The field cells and lab control columns containing disposal media only had an overall broad range of concentration extending from about 0.011 to 0.2 mg/L during the latter phases of operation. Interburden was again the exception, with a range of 9 to 21 mg/L.

Batch leaching of the Exxon and Alliance wastes yielded higher zinc concentrations than similar leaching of the disposal media, but leaching of the Georgetown waste had results similar to the disposal media results (at or near the detection limits). The Alliance field cells had generally lower zinc concentrations than either the Exxon cells or the cells containing disposal media only.

I.6 Survey of Concentration Trends During Attenuation/Mobilization

The basic chemical principles detailed in Section I.2 serve as the foundation for analysis of attenuation and mobilization behavior. The behavior of an adsorptive or ion exchange uptake from solution might be expected to follow classical uptake isotherm behavior. All comments made above regarding the distribution coefficient for release of waste constituents into the leaching fluid also apply to attenuation behavior. In addition, the soil character may change with time under prolonged contact with leachate and in different ways because of kinetic factors or mixing/abrasion factors or both.

I.6.1 Behavior Trends from the Batch Equilibration Protocol

I.6.1.1 Exxon PFBC Waste Leachate

When concentration-VPM curves from the attenuation part of the laboratory sequential batch equilibration protocol are interpreted, it must be remembered that solid disposal medium was exposed to waste leachate. Therefore, the highest VPM indicates the behavior due primarily to the waste leachate constituents while the lowest VPM show the effects of a large

quantity of disposal medium per volume of waste leachate. Step 4 concentrations provide data for $VPM = 10$; Step 5 data are plotted at $VPM > 10$, and Step 6 repetition data appear at $VPM < 10$.

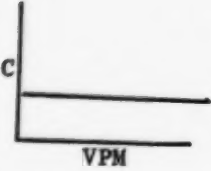
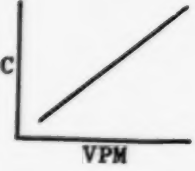
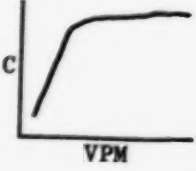
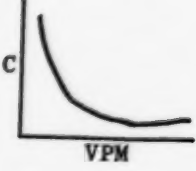
Table I-12 shows the behavior trends (curve shapes) observed for the concentrations as a function of VPM for attenuation/mobilization of Exxon PFBC waste leachate. One of the most common behavior trends observed in the interaction of waste leachate with disposal media was that of constant elemental concentration with increasing VPM (Trend A). A constant release could be indicative of several equilibrium mechanisms: dissolution/precipitation controlled reactions, adsorption/desorption reactions, or chelation/complexation reactions.

Another common behavior type is an increasing concentration with increasing VPM (Trend B). This behavior could indicate that the disposal medium could not sorb the total concentration of species available in the waste leachate, but sorbed only part of the available species in solution.

A third behavioral trend shown by several major species is characterized by low concentrations at low VPM with increasing concentration to a plateau for the highest VPM observed (Trend C). At high VPM the sorption capacity of the attenuating medium is exceeded and liquid phase concentration of species is not noticeably affected. At lower VPM the soil has adsorbed more and more of the species, and concentration in the liquid phase decreases.

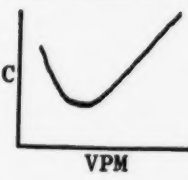
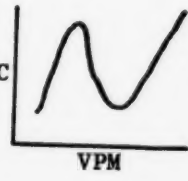
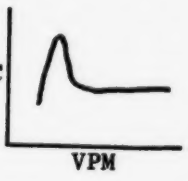
Disposal medium contribution is most likely responsible in trends demonstrating highest or moderately high concentrations at the lowest VPM; this trend exhibits two variations. The first type (Trend D) is characterized by a very rapid concentration decrease to some baseline concentration at the highest VPM. This behavior probably indicates that at low VPM, where the mass of disposal media (per volume) is greatest, the highest concentrations of the species released from the medium are observed. As the volume of waste leachate contacting the medium is increased, the individual species released from the medium is diluted and resultant lower concentrations are

TABLE I-12. BEHAVIOR TRENDS OBSERVED IN PLOTS OF CONCENTRATION VERSUS CUMULATIVE VOLUME OF EXXON PFBC WASTE LEACHATE PER MASS OF DISPOSAL MEDIUM FOR LABORATORY PROTOCOL ATTENUATION/MOBILIZATION

Curve Shape	Possible Mechanisms	Element/Species ¹	
	A. Low availability of species in waste and medium; or solubility-controlled release	As(8-14) Be(9-14) Cd(10,11,12) Cl(8-13) F(11) K(8-10,12-14) Mn(8-14) Mo(11)	Ni(11) SO ₄ (11) Se(8-14) TIC(8-14) TOC(8-14) U(8-14) V(11)
	B. Species distribution between solid and liquid phase is constant. Soil adsorbs a constant fraction of the species in the leachate	Ag(8,10,12) B(8,10,12) Co(8,11,13) Cr(12) Cu(10,12)	Fe(11) Ni(8,10,12) SO ₄ (12) V(13)
	C. Waste species is attenuated by medium at low VPM; graduated attenuation decreases with increasing VPM until complete breakthrough is achieved	Ba(8-10) Ca(8,9,10) Cu(8) F(13) M(8,10,12) Mn(13)	Ni(14) Pb(8,10-13) SO ₄ (13,14) Sr(8-10,12) V(14) pH(8-10 12-14)
	D. Species is contributed by medium and is diluted by increasing leachate volume	Al(9) Co(8) Cu(9) F(9,10,12,14) Fe(9,13,14) Mn(8-10,12,13)	Mo(9) Ni(9) SO ₄ (9) Si(9,13,14) V(8-10,12) Zn(8-10)

(Continued)

TABLE I-12. (Continued)

Curve Shape	Possible Mechanisms	Element/Species	
	E. Complex behavior; possible contribution from waste and medium undergoing sorption/desorption; possible complexation or precipitation of amphoteric species	Al(12) F(8) Na(8-10,13,14) Si(8,10,12) SO ₄ (8,10)	Sp. Cond(8-10,12-14) TDS(8-10,12-14) Ti(8,9,11) Zn(12)
	F. Complex behavior; possible sorption desorption cycling due to unknown chemical reactions	Ba(12-14) Cr(9,10)	Sr(13,14)
	G. Complex behavior; possible delayed contribution of medium at a specific solution condition	Ag(13) Be(8) Cd(8,13) Co(13) Cr(11,13,14) Cu(13)	Fe(8,10,12) Li(8,12-14) Mo(13) Ni(13) Zn(13)

¹Number in parentheses after species indicates medium for which behavior of element was observed when interacted with Exxon PFBC waste leachate. The number of each medium corresponds to the following sampling code:

- 8 = Shale
- 9 = Mine Interburden
- 10 = Sandstone
- 11 = Greer Limestone
- 12 = Glacial Till
- 13 = Alluvium
- 14 = Greenbriar Limestone

observed. It is remotely possible that solution conditions at high VPM's are favorable for species stabilization and unfavorable at low VPM's due to solution chemistry (e.g., pH ranges, possible complexation, etc).

The second type of curve (Trend E) also probably indicates initial contribution from the medium. It involves an initially moderate value for concentration, but also indicates a larger waste contribution at highest VPM. Between these two parts of the curve, an inflection occurs which results in a "parabola-shaped" curve. This complex behavior may be the result of sorption/desorption; the medium first loses its available quantity of the species, and then, as solution chemistry changes, the medium re-sorbs the species, only to release it again as the VPM increases.

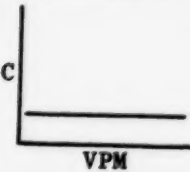
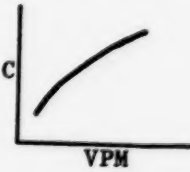
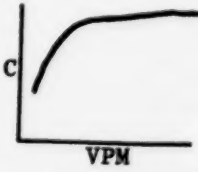
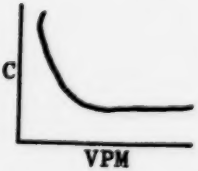
Perhaps the most complicated behavioral trend observed (Trend F) incorporates a similar mechanism. For several elements, the concentration starts low, goes high, rapidly decreases, then increases again producing almost a complete doublet of peaks as VPM increases to its maximum value. This cycling in concentration may be caused by sorption/desorption or complex behavior.

The final behavior trend illustrated in Table I-12 (Trend G) resembles a chromatographic release for a species with low retention. Concentration is lowest at the lowest VPM, passes through a maximum, and then returns to the original level as VPM increases. Most elements exhibiting this behavior had a generally low concentration, so that analytical variability could have caused an artifact in the curve of one value or more near the same analysis date. However, it is also possible that this behavior was a delayed contri-chemistry for release. Once the species was liberated from the medium, it became diluted at higher VPM's. Since the release was small, concentration returned to a minimum near instrumental detection limits.

I.6.1.2 Alliance AFBC Waste Leachate

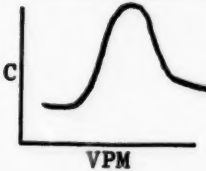
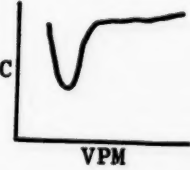
The behavior trends observed in the attenuation curves for the Alliance AFBC leachate are summarized in Table I-13. Explanation and speculations of

TABLE I-13. BEHAVIOR TRENDS OBSERVED IN PLOTS OF CONCENTRATION VERSUS CUMULATIVE VOLUME OF ALLIANCE AFBC WASTE LEACHATE PER MASS OF DISPOSAL MEDIUM FOR LABORATORY PROTOCOL ATTENUATION/MOBILIZATION

Curve Shape	Possible Mechanisms	Element/Species ¹	
	A. Low availability of species in waste and medium; solubility-controlled release	As(8-10, 11-14) F(13) K(8-10, 11-14) Pb(8-10, 11-14)	Se(8-10, 11-14) TOC(8-10, 11-14) TIC(8-10, 11-14) U(8-10,11-14)
	B. Species distribution between solid and liquid phase is constant. Soil adsorbs a constant fraction of the species in the leachate	Ag(8,9,12-14) Al(12-14) B(3) Cd(8,10) Co(8,12) Cu(8,10,12-14)	Fe(14) Mn(14) Ni(8) Ti(10,12-14) V(8,12,14)
	C. Waste species is attenuated by medium at low VPM; graduated attenuation decreases with increasing VPM until complete break-through occurs	B(12-14) Ba(8-10) Ca(8,9,12-14) Cd(12-14) Cl(8,9) Co(13,14) Cr(12-14) Li(8,10,13, 14) Mo(8-10,13)	Ni(12-14) pH(8-10, 12-14) SO ₄ (13,14) Sp. Cond (12-14) Sr(8-10, 12-14) V(13) Zn(12-14)
	D. Species is contributed by medium and is diluted by increasing waste leachate volume	Al(9) Ba(14) Ce(11-13) Co(9,10) F(8,10, 12,14) Fe(9,10,12) Mn(8-10,13)	Mo(14) Na(8-10, 12-14) Ni(9) SO ₄ (9) Si(8-10, 12-14) Zn(9)

(Continued)

TABLE I-13. (Continued)

Curve Shape	Possible Mechanisms	Element/Species	
	E. Complex behavior; possibly delayed contribution of medium at a specific solution condition; possibly sorbed species is desorbed from medium then diluted at high VPM	Ba(13) Be(8-10, 12-14) F(9) Fe(8)	Mo(12) V(8-10, 12-14) Zn(8)
	F. Complex behavior; contributions from waste and medium	Al(8,10) B(8,9) Ba(12) Cond(8-10) Cr(8-10) Li(9) Mn(12) Na(13)	Ni(10) SO ₄ (8,10,12) TDS(8-10, 12-14) Ti(8,9) V(9) Zn(10)

¹Numbers in parentheses after species indicates medium for which behavior of element was observed when interacted with Alliance AFBC waste leachate. The number for each medium corresponds to the following sampling code:

- 8 = Shale
- 9 = Mine interburden
- 10 = Sandstone
- 11 = Greer limestone
- 12 = Glacial Till
- 13 = Alluvium
- 14 = Greenbriar limestone

behavior trends presented previously for the Exxon PFBC leachate attenuation curves apply to the Alliance AFBC curves and are not repeated.

One trend not observed previously in the attenuation of PFBC waste leachate was quite common for the Alliance AFBC waste leachate attenuation (Trend F). It consists of an initial near-maximum value for concentration which rapidly decreases to a minimum and increases back to a plateau near the original maximum as VPM increases. This trend is probably best explained in terms of contributions from the medium with an intermediate stabilization due to sorption or complexation.

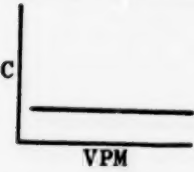
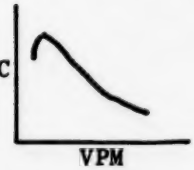
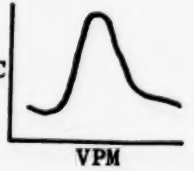
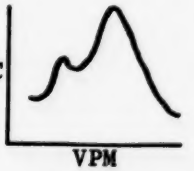
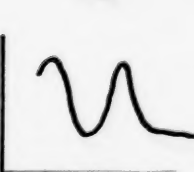
I.6.2 Behavior Trends in Laboratory Leaching Columns

Two laboratory column leaching arrangements containing layers of Exxon PFBC waste with shale and Alliance AFBC waste with sandstone were monitored (Figure I-4). Six types of attenuation/mobilization behavior trends were observed for the two column experiments (Table I-14). The only element remaining constantly low was potassium (Trend A). Several species appeared to be highly soluble and availability released by medium indicating dissolution or desorption (Trend B). The last four attenuation trends shown in Table I-13 are indicative of complex leaching behavior in which sorption/desorption or solubility-controlled behavior were responsible for combined behaviors included delayed release, release from different species, and separate releases from waste and medium.

I.6.3 Behavior Trends in Field Cells

A summary of the curve shapes resulting from plots of leachate concentration as a function of volume per mass for the field cells is given in Table I-15. Many species in this system show no concentration changes over the study duration (Trend A). These constant releases can be the result of several simple mechanism plateaus, including dissolution/precipitation, adsorption/desorption, and chelation/complexation. Some species appeared to be released from the medium with high initial concentrations which rapidly decreased (Trend B).

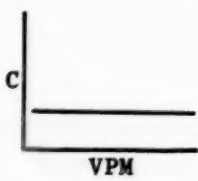
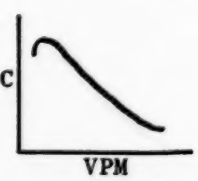
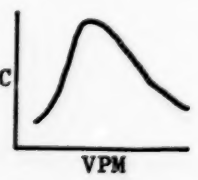
TABLE I-14. BEHAVIOR TRENDS OBSERVED IN PLOTS OF CONCENTRATION VERSUS CUMULATIVE VOLUME OF ELUANT PER MASS OF DISPOSAL MEDIUM IN LAB LEACHING COLUMN ATTENUATION/MOBILIZATION

Curve Shape	Possible Mechanism	Element/Species ¹	
	A. Species in low concentration in medium	K(5)	
	B. Probably availability controlled release of species highly concentrated in disposal medium	Cl(4,5) F(4,5) Mg(4)	Sp. Cond.(4) Sr(4,5) TDS(4)
	C. Initial attenuation followed by availability-controlled release of soluble species	Be(4,5) Co(4,5) Mg(5) Mn(4,5) Ni(4)	SO ₄ (4) Sp. Cond.(5) TDS(4,5) TDS(5)
	D. Complex behavior; initial attenuation, followed by breakthrough; possibly sorption-desorption cycling or contribution from dual species or separate contributions from medium and waste	B(4,5) Ba(4,5) Cu(4,5) Fe(4) K(4) Li(4,5)	Na(4,5) pH(4) SO ₄ (5) Ti(4,5) V(4,5) Zn(4,5)
	E. Complex behavior; contributions from medium and waste with possible sorption-desorption cycling	Al(4,5)	Cr(4,5)
	F. Complex behavior; probably contributions from medium followed by delayed waste contribution; sorption-desorption cycling possible, solubility-limited behavior possible	Ca(4,5) Cd(4,5) Fe(5)	Ni(5) pH(5) Si(4,5)

¹Number in parentheses following species indicates column number and following column arrangement (see Figure I-4):

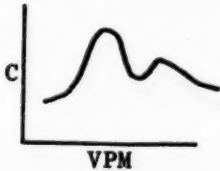
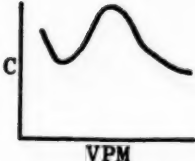
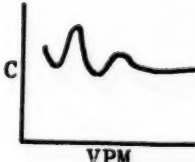
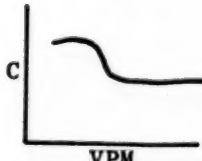
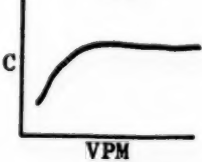
- 4: Column LC-4 = sandstone over Alliance AFBC waste over sandstone
5: Column LC-5 = shale over Exxon PFBC waste over shale

TABLE I-15. BEHAVIOR TRENDS OBSERVED IN PLOTS OF CONCENTRATION VERSUS CUMULATIVE VOLUME OF ELUENT PER MASS OF DISPOSAL MEDIUM FOR ATTENUATION/MOBILIZATION IN FIELD CELLS (LOWER SAMPLE POINT)

Curve Shape	Possible Mechanisms	Element/Species ¹	
	A. Constantly high concentrations indicate solubility limited behavior; constantly low values are due to low leachate concentrations of species in medium and waste	Al(1-7,12, 14-17) B(1-7,12, 14-17) Be(1-7,12, 14-17) Ca(2,4,6) Cd(1-5,12, 14-17) Cl(1,2,5, 6,7,12) Co(1-6,12, 14-17) Cond(7,12) Cu(1-7,12, 14-17) F(1,2,5,6, 7,12,17) Fe(1-7, 12-14-17) K(14,15)	Li(1-3,5-7, 12) Mg(7,12, 14,15) Mn(1-4,7,14, 16,17) Mo(1-7,12, 14-17) Na(1,2,7,12, 14,15) Ni(1-7,12, 14-17) pH(1-4,5,7, 13,16,17) SO₄(1-3,7, 12,14-17) Sr(1-7,12,14) TDS(1,2,3,5, 7,12-14) Zn(1-7,12, 14-17)
	B. Availability-controlled release of soluble species from medium or combination of contribution with the waste	Ca(16) Cl(4,13,16, 17) Li(4) Mn(6) SO₄(4,6)	Sp. Cond.(4, 6,16,17) Sr(13,16) TDS(4,6) Ti(14,15)
	C. Initial attenuation followed by breakthrough of availability-controlled release of species; possibly a delayed release from the medium	Al(13) B(13) Be(13) Ca(2,12) Cd(7,12) Co(13) F(3) K(7,12,13, 16,17)	Li(17) Mo(13) Na(3,5,13, 17) SO₄(5) Si(1-7,12, 14,15) V(5,15)

(Continued)

TABLE I-15. (Continued)

Curve Shape	Possible Mechanisms	Element/Species	
	D. Complex behavior; initial attenuation followed by breakthrough of two species or separate medium and waste contributions; could reflect sorption-desorption or solubility-controlled behavior	Cd(13) Cr(7,12,13) Cu(13) F(13) K(1,2,4,6) Li(3,16) Ni(13) pH(5)	SO ₄ (13) Si(13,16,17) Sr(17) TDS(1,3) Ti(1-7,12,13,16,17) V(1-4,7) Zn(13)
	E. Complex behavior; possibly high initially due to availability-controlled release from medium, followed by later surge from waste contribution; behavior could also reflect sorption-desorption or solubility-controlled behavior	Mg(1,2,4,6,13) Mn(13,17)	Na(4,6) V(12,14,16,17)
	F. Complex behavior; possibly sorption-desorption cycling or contribution by several species in medium and waste	Cr(1-6,14-17)	
	G. Solubility-limited behavior of species probably contributed from medium and waste	Ca(1-7,17) Fe(13)	K(3)
	H. Solubility-limited breakthrough after initial attenuation	Ca(3,5,13-15) Cl(3,14,15) F(4,14) K(5)	Mg(3,5,15,17) pH(12,14) Sp. Cond(1-3,5,13-15)

(Continued)

TABLE I-15. (Continued)

Curve Shape	Possible Mechanisms	Element/Species
OTHERS	I. Complex behaviors	Ba(1-7,12-13) V(6,13) H(5)

¹Numbers in parentheses indicate field cell number for which species behavior was observed. These field cells contained the following:

- Cell 1 - Exxon PFBC Waste and Shale
- Cell 2 - Exxon PFBC Waste and Shale
- Cell 3 - Exxon PFBC Waste and Till
- Cell 4 - Exxon PFBC Waste and Limestone
- Cell 5 - Exxon PFBC Waste and Alluvium
- Cell 6 - Exxon PFBC Waste and Sandstone
- Cell 13 - Alliance AFBC Waste and Interburden
- Cell 14 - Alliance AFBC Waste and Alluvium
- Cell 15 - Alliance AFBC Waste and Alluvium
- Cell 16 - Alliance AFBC Waste and Limestone
- Cell 17 - Alliance AFBC Waste and Shale

Increasing concentrations could be the result of dissolution or desorption. Initial attenuation of waste leachate by the medium followed by breakthrough of availability-controlled release was also observed for a number of species. Decreasing concentrations may indicate adsorption, redox, precipitation or chelation reactions in the leachate. Solubility-controlled release from the medium and from the waste were observed. Several additional complex behaviors were exhibited; the most frequently observed had two surges of breakthrough.

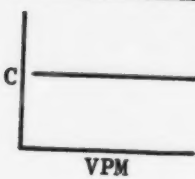
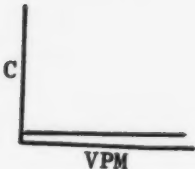
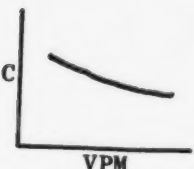
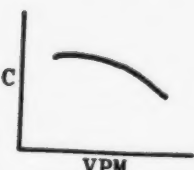
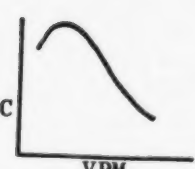
I.6.4 Behavior Trends in Laboratory Control Columns (Disposal Media)

Some of the most complicated curve shapes were exhibited by leachate concentration trends for the laboratory control columns, which exhibited 21 different behavior trends (Table I-16). The complexity of the media leachate trends explains the complex interaction observed for waste leachate eluting through media. However, column operational conditions may also include the additional complicating factor of possible biological growth. Similarities of leaching for media and waste are apparent and usually related by species.

I.6.5 Comparison of Batch Equilibration, Lab Column, and Field Cell Attenuation Trends

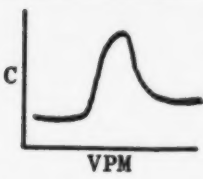
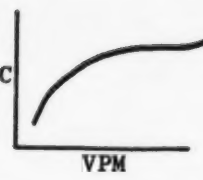
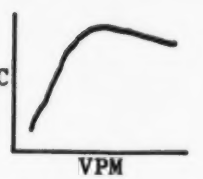
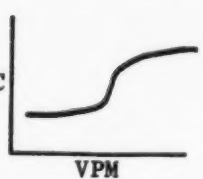
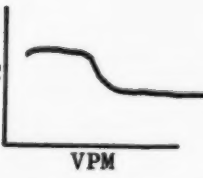
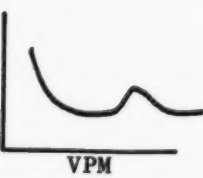
The same general curve shapes were observed for attenuation by all three extraction methods. For a given method of exposure of leachate to disposal media, many elements behaved in a similar manner for attenuation and leaching, indicating that mobilization of contaminants in the medium was common. In cross-comparison of curve shapes, lab column leaching more closely simulated field extraction than did sequential batch extraction. No correlations between groups in the periodic table and leaching behavior could be established. Basic curve shapes seen for the low VPM ranges in the field and column extractions were not very different from those for a low VPM batch leaching.

TABLE I-16. BEHAVIOR TRENDS OBSERVED IN PLOTS OF CONCENTRATION VERSUS CUMULATIVE ELUANT VOLUME IN LAB CONTROL COLUMN LEACHING OF MEDIA ALONE

Curve Shape	Possible Mechanisms	Species ¹	
	A. Solubility-limited	Ba(C) Ca(D) Co(F) Cu(C)	SO ₄ (C,F) Ti(C)
	B. Low availability of leachable species in medium	B(C) Be(C,D) Cd(D,E) K(C)	Mg(C) Na(A) Sr(F)
	C. Gradual decrease; possibly solubility-limited	Fe(C) Sp. Cond.(C)	Li(D) TDS(C,F)
	D. Gradual decrease; possibly solubility-limited	pH(C)	Sp. Cond.(C)
	E. Availability-limited	Co(D) Cu(D) Ma(D) SO ₄ (D)	Sp. Cond(D,E) TDS(D) TOC(C) Zn(D)
	F. Availability-limited	Cl(D) F(A,E,F) K(D) Mg(A,D) Mo(D) Ni(C,D,E)	Si(C) Sr(B,C,D) TDS(B) TOC(A,C) TOC

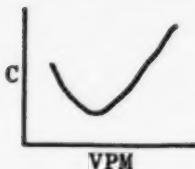
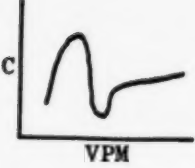
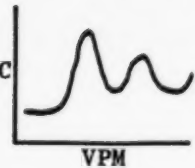
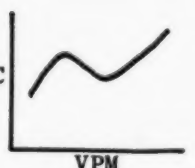
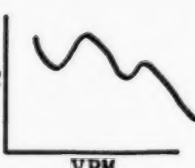
(Continued)

TABLE I-16. (Continued)

Curve Shape	Possible Mechanisms	Species ^a	
	G. Species undergoes delayed release. May be retained until solution chemistry provides proper pH, ionic strength, or other species in solution. Chromatographic type behavior.	B(A,B) Co(E) Cr(A,B,E) Cu(A,B,E) Fe(A,D)	Li(A) Si(A,B,D) Ti(A,B,D,E) V(D)
	H. Solubility-limited; initial attenuation of species	Al(A,B,C) Ca(B,C) Co(C)	Mn(F) V(C)
	I. Solubility-limited; initial attenuation of species	Cl(A) MO(C)	SO ₄ (B)
	J. Solubility-limited with initial attenuation	Al(F) B(F) Ba(F) Ca(F) Cd(F) Cr(F) Cu(F)	Fe(F) Mg(F) Mo(F) Ti(F) V(F) Zn(A)
	K. Solubility-limited with elapsed attenuation	K(F) Mn(C)	Ni(F)
	L. Complex-behavior; initially behavior appears to be availability of soluble species with residual delayed release	F(B,D) K(B)	Sp. Cond.(A) TDS(A)

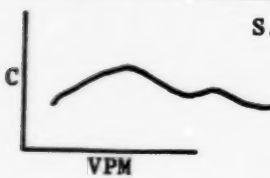
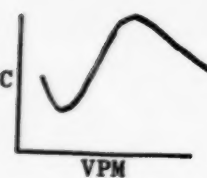
(Continued)

TABLE I-16. (Continued)

Curve Shape	Possible Mechanisms	Species ^a	
	M. Complex behavior; solution chemistry changed to cause rise in pH at higher volumes	pH(A)	
	N. Complex behavior	pH(B,D,E)	
	O. Complex behavior	Ba(A,D,E) Fe(E)	Mg(E) Si(E)
	P. Gradual dissolution	Zn(F)	
	Q. Complex behavior	SO ₄ (A)	
	R. Complex behavior	Mo(E)	

(Continued)

TABLE I-16. (Continued)

Curve Shape	Possible Mechanisms	Species ^a	
	S. Release to two species probably solubility-controlled	Na(C,D)	Mn(A)
	Complex behavior	Al(E) B(E) Be(D) Co(A,B) MO(A,B) Na(F)	Ni(B) Si(F) TOC(F) V(B,E) Zn(B)

^aLetter in parentheses after species indicates disposal medium as follows:

A = sandstone
 B = shale
 C = alluvium
 D = interburden
 E = limestone
 F = glacial till

I.7 Comparison to Water Quality Standards and Criteria

In order to gain insight into the relative degree of hazard that FBC waste leachate may pose to human health and the environment, a comparison was made between leachate concentrations of several species and corresponding limits established by various standards and criteria. This comparison was made for the batch equilibration protocol and field cell components of the program.

Several investigations have been performed on the hazard posed by various concentrations of most environmental contaminants (both at the point of emission or discharge and after dilution). Opinion concerning "safe" discharge and ambient concentrations is quite varied. A survey of several authoritative sources was performed to establish the basis of comparison for FBC waste leachates. These sources include the Primary and Secondary Drinking Water Regulations (References I-2 and I-3), Resource Conservation and Recovery Act Regulations (Reference I-4), and the Quality Criteria for Water (Reference I-5). The Multimedia Environmental Goals (Reference I-6) are included as potential indicators of monitoring trigger levels.

Table I-17 sets forth the limits established in these sources for the important parameters in FBC waste leachate. Also shown in Table I-17 is the most stringent standard or criterion from the sources reviewed. This most stringent standard was used in the comparison for FBC waste leachates. In some instances, the most stringent value may not be applicable to likely avenues of FBC waste leachate discharge to the environment. The purpose of drawing a comparison in those instances is to emphasize where the FBC leachate concentrations do not exceed even the most stringent value. For many of the parameters, the most stringent criterion possibly is too low and could be increased to allow for dilution of FBC leachate in the environment.

I.7.1 Comparison of Laboratory Batch Equilibration Protocol Results with Standards and Criteria

Separate comparisons with standards are made for the leachate generation and attenuation/mobilization portions at the laboratory protocol.

TABLE I-17. WATER QUALITY STANDARDS AND CRITERIA REFERENCED FOR FBC WASTE LEACHATE QUALITY COMPARISONS

Element/ Species	Primary or Secondary Drinking Water Regulation	RCRA Limits ¹	Quality Criteria for Water		Multimedia Environmental Goal (Discharge) ⁵		Most Stringent Criterion
			Domestic Water Supplies (Health)	Freshwater Aquatic Life	Health	Ecology	
Al	-	-	-	-	8.0	1.0	1.0
As	0.05 (P)	5.0	0.05	-	0.25	0.05	0.05
B	-	-	-	-	47	25	0.75 ⁷
Ba	1.0 (P)	100.0	1.0	-	5.0	2.5	1.0
Ca	-	-	-	-	240	16	16.0
Cd	0.01 (P)	1.0	0.01	0.04 ²	0.05	0.001	0.001
Cl	250 (S)	-	250 ³	-	-	-	250
Co	-	-	-	-	0.75	0.25	0.25
Cr	0.05 (P)	5.0	0.05	1.0	0.25	0.25	0.05
Cu	1 (S)	-	1.0 ⁴	-	5.0	0.05	0.05
F	2.0 @ 60°F (P)	-	-	-	-	-	2.0 @ 60°F
Fe	0.3 (S)	-	0.3 ⁴	1.0	-	-	0.3
K	-	-	-	-	30	43	30
Li	-	-	-	-	0.33	0.375	0.33
Mg	-	-	-	-	90	87	87
Mn	0.05 (S)	-	0.05 ⁴	-	0.25	0.1	0.05
Mo	-	-	-	-	75	7.0	7.0
Ni	-	-	-	-	0.23	0.01	0.01
Pb	0.05 (P)	5.0	0.05	-	0.25	0.05	0.05
pH	6.5-8.5 (S)	-	5-9	6.5-9.0	-	-	6.5-8.5
Se	0.01 (P)	1.0	0.1	-	0.05	0.025	0.01
SO ₄	250 (S)	-	250 ³	-	-	-	250
Sr	-	-	-	-	46	-	46
TDS	500 (S)	-	250 ³	-	-	-	250
Ti	-	-	-	-	90	0.82	0.82
V	-	-	-	-	-	-	-
Zn	5 (S)	-	5.0 ⁴	-	2.5	0.15	0.15
					25	0.1	0.1

¹RCRA = Resource Conservation and Recovery Act Regulations; 100 times the Primary Drinking Water Standard for Metals.

²For soft, not hard fresh water.

³For less sensitive aquatic life in soft water.

⁴Welfare, not health criterion.

⁵250 mg/L is the criterion for chloride and sulfate (total) in domestic water supplies (welfare).

⁶Based on Minimum Acute Toxicity Effluent Level.

⁷Based on Q/LW long-term irrigation of sensitive crops.

I.7.1.1 Laboratory Leaching Comparison Results

The comparison of laboratory leaching results was achieved by tabulating the percentage of data points from Steps 1 and 2 of the protocol which exceeded each of the most stringent criteria. The results of this tabulation are shown in Table I-18. The total number of individual concentration values examined is presented for each waste followed by the percent of the total which exceeds the standard given.

From Table I-18 it is apparent that leachate concentrations of some elements do not exceed the most severe criterion for discharge to the environment. Co, F, Mg, Mn, Mo, and Ti concentrations were always below the most severe criterion for all Step 1 and Step 2 batch leachates for all three of the FBC wastes.

Species which exceeded the criterion values for all samples generally exceeded the values by a large margin. Ca, pH, SO₄, and TDS always exceeded the criterion values for all samples and for all three wastes.

The remaining species concentrations (B, Ba, Cd, Cr, Cu, K, Li, Ni, V, and Zn) were variable relative to the criterion values. Appreciable fractions of leachate concentrations would exceed the criterion value for one species for one (or two) wastes but not the other two (or one). Chromium, for example, showed 48, 81, and 21 percent of samples above the criterion value for Exxon PFBC, Alliance AFBC and Georgetown AFBC wastes, respectively. Boron was high in the Exxon and Alliance leachates (100% and 92% exceeded, respectively) but much lower in the Georgetown leachate (18% exceeded).

For a few species, analytical detection limits exceeded the criterion values and only those values that were greater than the detection limit were counted as exceeding the criterion value. These were arsenic (DL = 0.08, criterion = 0.05 mg/L), cadmium (DL = 0.005, criterion = 0.001 mg/L), nickel (DL = 0.02, criterion = 0.015 mg/L), lead (DL = 0.07, criterion = 0.05

TABLE I-18. COMPARISON OF LABORATORY LEACHATE CONCENTRATIONS (STEPS 1 AND 2) WITH WATER QUALITY STANDARDS AND CRITERIA

Element Species	Most Stringent Standard or Criterion (mg/L)	Steps 1 and 2 of Laboratory Protocol					
		Exxon PFBC		Alliance AFBC		Georgetown AFBC	
		Number of Points	Percent Above Standard	Number of Points	Percent Above Standard	Number of Points	Percent Above Standard
Al	1.0	23	26	26	46	40	0
As ¹	0.05	22	0	0	-	0	-
B	0.75	23	100	26	92	40	18
Ba	1.0	23	0	26	0	40	38
Ca	16.0	23	100	24	100	39	100
Cd	0.001	23	0	26	92	40	18
Cl	250	19	0	26	0	40	0
Co	0.25	23	0	26	0	40	0
Cr	0.05	23	48	26	81	26	21
Cu	0.05	23	4.4	26	65	40	10
F	2.0 @ 60°F	23	4.4	26	0	40	0
Fe	0.3	23	8.7	26	0	40	0
K	30	23	0	26	38	40	0
Li	0.33	0	-	32	3.9	39	26
Mg	87	23	0	26	0	30	0
Mn	0.05	23	0	26	0	40	0
Mo	7.0	8	0	26	0	39	0
Ni ¹	0.01	23	13	26	92	40	25
Pb ¹	0.05	22	0	0	-	0	-
pH	6.5-8.5	24	100	26	100	40	100
Se ¹	0.01	22	0	0	-	0	-
SO ₄	250	24	100	26	100	40	30
Sr	46	23	0	24	0	40	0
TDS	250	24	100	26	100	40	100
Ti	0.82	23	0	26	0	40	0
V	0.15	23	0	26	54	40	2.5
Zn	0.1	23	52	26	0	40	0

¹Detection limit exceeds criterion value.

mg/L), potassium (DL = 40, criterion = 30 mg/L), and selenium (DL = 0.12, criterion = 0.01 mg/L).

I.7.1.2 Laboratory Attenuation/Mobilization Comparison Results

A similar comparison of the most stringent standards was made with leachate concentrations after exposure of the leachate to the six disposal media in Steps 4, 5, and 6 of the laboratory protocol.

Exxon PFBC Waste

The results of the comparison for Exxon PFBC waste are shown in Table I-19. This table shows that, as expected, the disposal medium exceeding the most stringent criterion most frequently was the interburden. Most of the chemical parameters had at least 30 percent of the data points above the standard for this medium.

The parameters that were most consistently above the most stringent standard (generally 50 percent or more of the data points) for all the media were B, Ca, Cr, Co, Cu, Ni, K, SO₄, pH, and TDS. The species that did not generally exceed the standard were Ba, Cl, F, Li, Mg, Mo, Sr, and Ti.

Comparison of Table I-19 with Table I-18 shows that, in general, exposure of the leachate to the disposal media caused the percent of data points which exceed the standard to increase rather than decrease. Only for boron, fluoride, pH, and zinc were the percentages that exceeded the standard reduced below the Step 1-2 leachate percentages consistently for all disposal media. The percentage of data points above the most stringent standard was increased (or remained constant) for all other parameters.

Alliance AFBC Waste

A similar tabulation for Alliance AFBC waste is presented in Table I-20. Comparison of this table with Table I-18 shows that the disposal media caused an increase in the percentage of values above the standard

TABLE I-19. COMPARISON OF LABORATORY ATTENUATION/MOBILIZATION RESULTS
(STEPS 4, 5, AND 6) WITH WATER QUALITY STANDARDS AND CRITERIA:
EXXON PFBC WASTE

Element/ Species	Most Stringent Standard or Criterion (mg/L)	Shale		Interburden		Sandstone		Glacial Till		Alluvium		Limestone	
		Number of Points	Percent Above Standard	Number of Points	Percent Above Standard	Number of Points	Percent Above Standard	Number of Points	Percent Above Standard	Number of Points	Percent Above Standard	Number of Points	Percent Above Standard
Al	1.0	26	42	26	62	26	31	26	31	26	50	24	67
B	0.75	26	31	26	65	26	38	26	65	26	46	24	63
Ba	1.0	26	0	26	0	26	0	26	0	26	0	24	0
Ca	16.0	26	96	26	100	26	100	26	100	26	100	24	100
Cd ^a	0.001	26	39	26	38	26	7.7	26	0	26	15	24	54
Cl	250	-	-	2	0	0	0	-	-	-	-	-	-
Co	0.25	26	46	26	88	26	54	26	54	26	54	24	100
Cr	0.05	26	62	26	77	26	42	26	58	26	54	24	71
Cu	0.05	26	69	26	73	26	50	26	54	26	54	24	71
F	2.0 @ 60°F	26	0	26	0	25	0	25	0	24	0	22	0
Fe	0.3	26	15	26	31	26	15	26	19	26	46	24	0
K ^a	30	26	69	26	92	26	96	26	54	26	54	24	100
Li	0.33	22	0	8	0	22	0	22	0	22	0	14	0
Mg	87	14	0	26	7.7	15	0	14	0	25	0	24	0
Mn	0.05	26	35	26	31	26	31	26	3.9	26	42	24	17
Mo	7.0	26	0	24	4.2	26	0	26	0	26	0	24	0
Ni ^a	0.01	26	88	26	92	26	88	26	54	26	73	24	100
pH	6.5-8.5	26	58	26	92	26	69	26	65	26	92	26	81
Se	0.01	-	-	2	0	-	-	-	-	-	-	-	-
SO ₄	250	26	100	26	100	26	100	26	100	26	100	26	100
Sr	46	26	0	26	0	26	0	26	0	26	0	24	0
TDS	250	26	100	26	100	26	100	26	100	26	100	25	100
Ti	0.82	26	0	26	0	26	0	26	0	26	0	24	0
V	0.15	26	42	26	65	26	27	26	19	26	35	24	83
Zn	0.1	26	3.9	26	38	26	0	26	0	26	3.9	24	0

Detection limit exceeds criterion value.

^aDetection limit exceeds criterion value.

TABLE I-20. COMPARISON OF LABORATORY ATTENUATION/MOBILIZATION RESULTS
(STEPS 4, 5, AND 6) WITH WATER QUALITY STANDARDS AND CRITERIA:
ALLIANCE AFBC WASTE

Element/ Species	Most Stringent Standard or Criterion (mg/L)	Shale			Interburden			Sandstone			Till			Alluvium			Limestone		
		Number of Points	Percent Above Standard	Number of Points	Number of Points	Percent Above Standard	Number of Points	Number of Points	Percent Above Standard	Number of Points	Number of Points	Percent Above Standard	Number of Points	Number of Points	Percent Above Standard	Number of Points	Number of Points	Percent Above Standard	
Al	1.0	30	30	32	32	72	32	32	38	32	32	28	32	32	44	32	32	47	
B	0.75	30	93	32	32	88	32	32	66	32	32	50	32	32	50	32	32	50	
Ba	1.0	30	0	32	32	0	32	32	0	32	32	0	32	32	0	32	32	0	
Ca	16.0	30	100	32	32	100	32	32	100	32	32	100	32	32	100	32	32	94	
Cd	0.001	30	87	32	32	88	32	32	69	32	32	50	32	32	50	32	32	50	
Cl	250	32	0	32	32	0	32	32	0	32	32	0	32	32	0	32	32	0	
Co	0.25	30	0	32	32	25	32	32	0	32	32	0	32	32	0	32	32	0	
Cr	0.05	30	80	32	32	81	32	32	56	32	32	50	32	32	50	32	32	50	
Cu	0.05	30	80	32	32	88	32	32	56	32	32	50	32	32	50	32	32	50	
F	2.0 @ 60°F	32	0	32	32	3.1	32	32	0	32	32	0	32	32	3.1	32	32	0	
Fe	0.3	30	0	32	32	22	32	32	0	32	32	3.1	32	32	3.1	32	32	0	
K	30	30	100	32	32	100	32	32	100	32	32	56	32	32	69	32	32	100	
Li	0.33	16	25	32	32	31	32	32	27	32	32	17	32	32	21	32	32	33	
Mg	87	30	3.3	32	32	9.4	32	32	0	32	32	3.1	32	32	0	32	32	3.1	
Mn	0.05	30	27	32	32	25	32	32	25	32	32	0	32	32	22	32	32	0	
Mo	7.0	30	0	32	32	0	32	32	0	32	32	0	32	32	0	32	32	0	
Ni ¹	0.01	30	97	32	32	88	32	32	88	32	32	78	32	32	88	32	32	78	
pH	6.5-8.5	32	75	32	32	75	32	32	75	32	32	69	32	32	75	32	32	81	
SO ₄	250	32	100	32	32	100	32	32	100	32	32	100	32	32	100	32	32	100	
Sr	46	30	0	32	32	0	32	32	0	32	32	0	32	32	0	32	32	0	
TDS	250	32	100	32	32	100	32	32	100	32	32	100	32	32	100	32	32	100	
Tl	0.82	30	0	32	32	0	32	32	0	32	32	0	32	32	0	32	32	0	
V	0.15	30	60	32	32	75	32	32	50	32	32	50	32	32	50	32	32	50	
Zn	0.1	30	0	32	32	25	32	32	0	32	32	0	32	32	0	32	32	0	

^aDetection limit exceeds criterion value.

(relative to the leachate prior to exposure to the disposal media) for K, Li, Mg, and Mn. Examination of Table I-20 shows that again the disposal medium having the highest percent above the standard for most parameters was the interburden.

For the Alliance AFBC waste leachate after exposure to the disposal media, the parameters that most frequently exceeded the standard (generally 50 percent or more of the data points) were B, Cd, Ca, Cr, Cu, Ni, K, SO₄, V, pH, and TDS. The parameters that seldom exceeded the standard were Ba, Cl, Co, F, Fe, Mg, Mo, Sr, Ti, and Zn.

Georgetown AFBC Waste

The results of the standards comparison for Georgetown AFBC waste are shown in Table I-21. This table differs significantly from the previous tables in that only two data points are presented for Step 4. Steps 5 and 6 of the protocol were not performed on this waste.

Because there are only two points, it is difficult to draw definitive conclusions concerning percentages above the standard for the Georgetown AFBC waste. In general, Ba, Cd, and Cu appeared to have lower percentages above the standard after exposure to the disposal media. SO₄ may have had a higher percent after exposure to the disposal media.

I.7.2 Comparison of Field Cell Leaching and Attenuation/Mobilization Results with Standards and Criteria

Comparisons similar to the laboratory results were performed for the field cells. Where the comparisons for leachate generation were made for the lab by using Steps 1 and 2 of the protocol, similar comparisons were made for the field cells by using leachate from the upper sampling point. Likewise, the attenuation/mobilization phase was evaluated by using leachates from the lower sampling point.

TABLE I-21. COMPARISON OF LABORATORY ATTENUATION/MOBILIZATION RESULTS
(STEPS 4, 5, AND 6) WITH WATER QUALITY STANDARDS AND CRITERIA:
GEORGETOWN AFBC WASTE

Element/ Species	Most Stringent Standard or Criterion (mg/L)	No Medium			Shale			Interburden			Sandstone			Till			Alluvium			Limestone		
		Number Points	Percent Above Standard	Number of Above Standard	Number Points	Percent Above Standard	Number of Above Standard	Number Points	Percent Above Standard	Number of Above Standard	Number Points	Percent Above Standard	Number of Above Standard	Number Points	Percent Above Standard	Number of Above Standard	Number Points	Percent Above Standard	Number of Above Standard	Number Points	Percent Above Standard	Number of Above Standard
Al	1.0	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
B	0.75	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Ba	1.0	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Ca	16.0	2	100	2	2	100	2	2	100	2	2	100	2	2	100	2	2	100	2	2	100	2
Cd ^a	0.001	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Cl	250	0	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Co	0.25	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Cr	0.05	2	100	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Cu	0.05	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
F	2.0 @ 60°F	-	-	-	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Fe	0.3	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
K ⁺	30	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Li	0.33	2	100	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Mg	87	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Mn	0.05	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Mo	7.0	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Ni ^a	0.01	2	50	2	2	50	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
pH	6.5-8.5	0	0	2	2	100	2	2	100	2	2	100	2	2	100	2	2	100	2	2	100	2
SO ₄	250	0	0	2	2	100	2	2	100	2	2	100	2	2	100	2	2	100	2	2	100	2
Sr	46	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
TDS	250	0	0	2	2	100	2	2	100	2	2	100	2	2	100	2	2	100	2	2	100	2
Tl	0.82	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
V	0.15	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
Zn	0.1	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2

^aDetection limit exceeds criterion value.

Exxon PFBC Field Cells

The percentages of data points from the upper sample point of the PFBC field cells which exceeded the most stringent standards are shown in Table I-22. There does not seem to be a large difference among the field cells in terms of the values of the percentages, which is expected inasmuch as the only difference among the cells is the upper layer of disposal medium. The parameters for which the standards were exceeded the most were B, Ca, Cr, Li, Mg (except for the field cell containing alluvium), Mn, Ni, K, SO₄, V, and TDS. The parameters for which the standards were exceeded the least were Ba, Cd, Cl, Co, Cu, F, Fe, Mo, Sr, Ti, and pH.

The results of the comparison with standards for leachates from the lower sampling point of the Exxon PFBC field cells are shown in Table I-23. The parameters for which the standards were exceeded the most were Al, B, Ca, Cr, Mg, Mn, Ni, K, SO₄, V, and TDS. The standards were exceeded least by Ba, Cl, Cu, F, Fe, Mo, Sr, Ti, and pH.

The results of the standards comparisons were remarkably similar for the upper and lower sampling points of the PFBC field cells. Passage of the leachate through the lower disposal medium layer caused a reduction in the percentage higher than the standard only for B, Cd (slight), Cl (slight), and Li. Increases in the percentage occurred for Al, Mg, K (slight), and Zn.

Alliance AFBC Field Cells

The results of the standards comparison for the upper sampling point at the AFBC field cells are shown in Table I-24. These results show that the standards were exceeded most frequently for B, Ca, Cl, Cr, Li, K, SO₄, and TDS. The standards were exceeded least for Ba, Co, F, Mg, Mo, Sr, Ti, and Zn.

The results of the comparisons for the lower sampling point data are presented in Table I-25. The percentage of points above the standard was

TABLE I-22. COMPARISON OF FIELD LEACHATE GENERATION RESULTS (UPPER SAMPLE POINT) WITH WATER QUALITY STANDARDS AND CRITERIA: EXXON PFBC FIELD CELLS

Element/ Species	Most Stringent Standard or Criterion (mg/L)	Cell 1 Shale			Cell 2 Shale			Cell 3 Glacial Till			Cell 4 Limestone			Cell 5 Alluvium			Cell 6 Sandstone		
		Number Points	Percent Above Standard	Percent Above Standard	Number Points	Percent Above Standard	Percent Above Standard	Number Points	Percent Above Standard	Percent Above Standard	Number Points	Percent Above Standard	Percent Above Standard	Number Points	Percent Above Standard	Percent Above Standard	Number Points	Percent Above Standard	Percent Above Standard
Al	1.0	29	17	0	30	20	6.7	29	14	17	30	6.7	28	11	29	17	29	100	100
B	0.75	29	100	0	30	100	0	29	97	0	30	100	28	100	29	0	29	0	0
Ba	1.0	29	0	0	30	0	0	29	0	0	30	0	28	3.6	29	0	29	0	0
Ca	16.0	29	100	0	30	100	0	29	100	0	30	100	28	100	29	0	29	0	0
Cd ^a	0.001	29	14	0	30	6.7	0	29	17	0	30	6.7	28	7.1	29	100	29	100	100
Cl	250	15	0	0	16	6.3	0	17	18	0	16	6.3	8	0	29	6.9	29	0	0
Co	0.25	29	6.9	0	30	20	6.7	29	10	0	30	0	28	11	29	0	29	0	0
Cr	0.05	29	66	0	30	70	0	29	62	0	30	53	28	25	29	48	29	48	48
Cu	0.05	29	14	0	30	6.7	0	29	6.9	0	30	6.7	28	7.1	29	6.9	29	6.9	6.9
F	2.0 @ 60°F	28	0	0	27	0	0	29	0	0	29	0	28	0	29	0	29	0	0
Fe	0.3	29	6.9	0	30	3.3	0	29	0	0	30	17	28	0	29	6.9	29	0	0
K ⁺	30	29	69	0	30	67	0	29	69	0	30	70	28	68	30	69	29	69	69
Li	0.33	12	58	0	11	36	0	12	83	0	12	67	11	100	12	67	12	67	67
Mg	87	29	52	0	30	63	0	29	48	0	30	37	28	3.6	29	48	29	48	48
Mn	0.05	29	83	0	30	87	0	29	79	0	30	80	28	54	29	83	29	83	83
Mo	7.0	29	0	0	30	0	0	29	0	0	30	0	28	0	29	0	29	0	0
Ni ^a	0.01	29	69	0	30	80	0	29	79	0	30	73	28	82	29	89	29	89	89
pH	6.5-8.5	28	0	0	28	3.6	0	29	17	0	29	0	28	32	29	6.9	29	6.9	6.9
SO ₄	250	28	100	0	27	100	0	29	100	0	29	100	28	100	29	100	29	100	100
Sr	46	29	0	0	30	0	0	29	0	0	30	0	28	0	29	0	29	0	0
TDS	250	28	100	0	27	100	0	29	100	0	29	100	28	100	29	100	29	100	100
Ti	0.82	29	0	0	30	0	0	29	0	0	30	0	28	0	29	0	29	0	0
V	0.15	29	62	0	30	63	0	29	62	0	30	63	28	25	29	62	29	62	62
Zn	0.1	29	17	0	30	43	0	29	21	0	30	10	28	7.1	29	17	29	17	17

^aDetection limit exceeds criterion value.

TABLE I-23. COMPARISON OF FIELD LEACHATE ATTENUATION/MOBILIZATION RESULTS
(LOWER SAMPLE POINT) WITH WATER QUALITY STANDARDS AND CRITERIA:
EXXON PFBC FIELD CELLS

Element/ Species	Most Stringent Standard or Criterion (mg/L)	Cell 1 Shale			Cell 2 Shale			Cell 3 Glacial Till			Cell 4 Limestones			Cell 5 Alluvium			Cell 6 Sandstone		
		Number of Points			Number of Points			Number of Points			Number of Points			Number of Points			Number of Points		
		Standard	Percent Above	Standard	Standard	Percent Above	Standard	Standard	Percent Above	Standard	Standard	Percent Above	Standard	Standard	Percent Above	Standard	Standard	Percent Above	Standard
Al	1.0	30	43	30	30	43	30	27	44	30	37	30	30	30	30	30	30	43	30
B	0.75	30	63	30	30	97	30	27	70	30	100	30	30	30	53	30	30	97	30
Ba	1.0	30	0	30	0	30	0	27	0	30	0	30	0	30	3.3	30	0	0	30
Ca	16.0	30	100	30	100	30	100	27	100	30	100	30	100	30	100	30	100	30	100
Cd ^a	0.001	30	3.3	30	3	3	3	27	11.11	30	6.7	30	3.3	30	3.3	30	3.3	30	3.3
Cl	250	16	0	18	0	18	0	14	0	17	47	15	0	15	0	9	0	0	0
Co	0.25	30	17	30	23	27	27	27	0	30	10	30	0	30	0	30	43	30	0
Cr	0.05	30	67	30	67	27	27	27	41	30	70	30	30	30	30	30	70	30	0
Cu	0.05	30	10	30	6.7	27	27	27	7.4	30	10	30	13	30	13	30	17	30	0
F	2.0 @ 60°F	29	0	30	0	26	0	26	0	29	6.9	29	0	29	0	30	0	30	0
Fe	0.3	30	0	30	0	27	0	27	0	30	3.3	30	0	30	0	30	0	0	0
K ^a	30	30	90	30	66	27	27	27	89	30	66	30	30	30	97	30	66	30	0
Li	0.33	12	0	12	8.3	12	12	12	33	12	42	12	12	12	8.3	12	100	100	0
Mg	87	30	83	30	87	27	27	27	74	30	87	30	20	30	20	30	87	30	0
Mn	0.05	30	60	30	60	27	27	27	67	30	83	30	30	30	97	30	80	30	0
Mo	7.0	30	0	30	0	27	0	27	0	30	0	30	0	30	0	30	0	0	0
Ni ^a	0.01	30	70	30	77	26	26	26	73	30	97	30	30	30	93	30	87	30	0
pH	6.5-8.5	29	0	30	0	26	0	26	0	29	0	27	27	27	59	30	0	0	0
SO ₄	250	29	100	30	100	26	100	26	100	29	100	29	76	30	76	30	100	100	0
Sr	46	30	0	30	0	27	0	27	0	30	0	30	0	30	0	30	0	0	0
TDS	250	29	100	30	100	26	100	26	100	29	100	28	93	30	93	30	100	100	0
Ti	0.82	30	0	30	0	27	0	27	0	30	0	30	3.3	30	3.3	30	0	0	0
V	0.15	30	67	30	67	27	27	27	63	30	73	30	27	30	27	30	77	30	0
Zn	0.1	30	27	30	30	27	27	27	30	30	50	30	43	30	43	30	87	30	0

^aDetection limit exceeds criterion value.

TABLE I-24. COMPARISON OF FIELD LEACHATE GENERATION RESULTS (UPPER
SAMPLE POINT) WITH WATER QUALITY STANDARDS AND CRITERIA:
ALLIANCE AFBC FIELD CELLS

Element/ Species	Most Stringent Standard of Criterion (mg/L)	Cell 13			Cell 14			Cell 15			Cell 16			Cell 17		
		Interburden		Percent Above Standard	Alluvium		Percent Above Standard	Alluvium		Percent Above Standard	Limestone		Percent Above Standard	Shale		Percent Above Standard
		Number of Points	Standard		Number of Points	Standard		Number of Points	Standard		Number of Points	Standard		Number of Points	Standard	
Al	1.0	21	19		12	42		16	31		24	13		24	38	
B	0.75	21	52		12	58		16	75		24	54		24	75	
Ba	1.0	21	4.8		12	8.3		16	6.3		24	0		24	4.2	
Ca	16.0	21	86		12	67		16	44		24	63		24	54	
Cd ^a	0.001	21	14		12	17		16	19		24	8.3		24	17	
Cl	250	21	38		12	50		16	75		24	33		24	54	
Co	0.25	21	0		12	0		16	0		24	0		24	0	
Cr	0.05	21	43		12	58		16	81		24	54		24	42	
Cu	0.05	21	14		12	25		16	13		24	25		24	29	
F	2.0 @ 60°F	21	0		12	0		16	0		24	0		24	0	
Fe	0.3	21	19		12	58		16	31		24	13		24	4.2	
K ^a	30	21	95		12	83		16	94		24	100		24	100	
Li	0.33	21	100		12	100		16	100		24	100		24	83	
Mg	87	21	0		12	0		13	0		24	0		24	0	
Mn	0.05	21	43		12	58		16	13		24	54		24	42	
Mo	7.0	21	0		12	0		16	0		24	0		24	0	
Ni ^a	0.01	21	43		12	50		16	25		24	46		24	46	
pH	6.5-8.5	21	33		12	17		16	63		24	42		24	38	
SO ₄	250	21	100		12	100		16	100		24	100		24	100	
Sr	46	21	0		12	33		16	6.3		24	17		24	8.3	
TDS	250	21	100		12	100		16	100		24	100		24	100	
Ti	0.82	21	0		12	0		16	0		24	0		24	0	
V	0.15	21	14		12	25		16	13		24	13		24	25	
Zn	0.1	21	0		12	0		16	0		24	0		24	13	

^aDetection limit exceeds criterion value.

TABLE I-25. COMPARISON OF FIELD LEACHATE ATTENUATION/MOBILIZATION RESULTS
(LOWER SAMPLE POINT) WITH WATER QUALITY STANDARDS AND CRITERIA:
ALLIANCE AFBC FIELD CELLS

Element/ Species	Most Stringent Standard of Criterion (mg/L)	Cell 13			Cell 14			Cell 15			Cell 16			Cell 17		
		Interburden		Number of Points	Alluvium		Number of Points	Alluvium		Number of Points	Limestone		Number of Points	Shale		Number of Points
		Number	Percent Above Standard		Number	Percent Above Standard		Number	Percent Above Standard		Number	Percent Above Standard		Number	Percent Above Standard	
Al	1.0	23	74	16	39	5.6	20	50	24	83	23	87	23	23	87	23
B	0.75	23	91	16	38	5.6	20	42	24	87	23	68	23	23	68	23
Ba	1.0	23	0	16	100	5.6	20	25	24	4.2	23	0	23	23	0	23
Ca	16.0	23	100	16	100	5.6	20	100	24	100	23	100	23	23	100	23
Cd ¹	0.001	23	83	16	5.6	5.6	20	5.0	24	21	23	17	23	23	17	23
Cl	250	21	38	17	33	5.6	20	85	24	50	23	57	23	23	57	23
Co	0.25	23	100	16	0	5.6	20	0	24	0	23	0	23	23	0	23
Cr	0.05	23	35	16	11	5.6	20	15	24	46	23	48	23	23	48	23
Cu	0.05	23	96	16	5.6	5.6	20	5.0	24	30	23	30	23	23	30	23
F	2.0 @ 60°F	21	100	17	0	5.6	20	0	24	0	23	0	23	23	0	23
Fe	0.3	23	96	16	61	5.6	20	10	24	13	23	13	23	23	13	23
K ¹	30	23	96	16	0	5.6	20	0	24	100	23	91	23	23	91	23
Li	0.33	23	100	16	0	5.6	20	0	24	100	23	13	23	23	13	23
Mg	87	23	100	13	5.6	5.6	20	0	24	71	23	74	23	23	74	23
Mn	0.05	23	100	16	83	5.6	20	85	24	83	23	70	23	23	70	23
Mo	7.0	23	13	16	0	5.6	20	0	24	0	23	0	23	23	0	23
Ni ¹	0.01	23	100	13	78	5.6	20	85	24	83	23	43	23	23	43	23
pH	6.5-8.5	21	100	17	78	5.6	20	55	24	0	23	0	23	23	0	23
SO ₄	250	21	100	17	44	5.6	20	25	24	100	23	100	23	23	100	23
Sr	46	22	0	16	0	5.6	20	0	24	4.2	23	0	23	23	0	23
TDS	250	21	100	17	89	5.6	20	95	24	100	23	100	23	23	100	23
Ti	0.82	23	0	16	0	5.6	20	0	24	0	23	0	23	23	0	23
V	0.15	23	78	16	5.6	5.6	20	5.0	24	21	23	17	23	23	17	23
Zn	0.1	23	100	16	39	5.6	20	35	24	33	23	35	23	23	35	23

¹Detection limit exceeds criterion value.

highest for Al, B, Ca, Cl, Mg (inconsistent for different field cells), Mn, Ni, K (inconsistent for different field cells), SO₄, and TDS. The parameters with the lowest percentages were Ba, Co¹, F¹, Li¹, Mo, K, Sr, and Ti.

A comparison of the results for the upper and lower sampling points shows that exposure of the leachate to the lower layer of disposal media caused the percentage above the standard to decrease for Cr (slight), Li (except for the field cells containing interburden and limestone), Sr (slight), SO₄ (slight), and pH (except for field cells containing interburden and alluvium). The percentages increased for Al, Ba (slight), Ca, Mg, and Zn.

Control (Media Only) Field Cells

The role of the disposal media in causing the most stringent standard to be exceeded can be evaluated by comparing the leachate from the control field cells to the most stringent standard directly (Table I-26). This comparison showed that leachate from shale generally exceeded the standards for Ca, Cr, Mg, Mn, Ni, K, SO₄, V, Zn, and TDS. For alluvium, the standards were exceeded for Ca, Mn, and Ni. The standards were generally met for both the shale and alluvium for Ba, Cl, F, Fe, Li, Mo, Sr, and Ti.

I.7.3 Summary of Comparison to Water Quality Standards and Criteria

A summary of the foregoing analyses is presented in Table I-27, which contains the parameters for which the most stringent standard was consistently exceeded or was consistently not exceeded for each component of the laboratory and field programs.

This table shows that several parameters exceeded the standards in almost all phases of the study (both lab and field), including B, Ca, Cr, SO₄, and TDS. The standard for pH was exceeded in all phases of the lab investigation, and K, Mn, and Ni generally exceeded the standard for all

¹Except for field cell containing interburden.

TABLE I-26. COMPARISON OF LEACHATE FROM FIELD CONTROL CELLS (CONTAINING DISPOSAL MEDIA ONLY) WITH WATER QUALITY STANDARDS AND CRITERIA

Element/ Species	Most Stringent Standard of Criterion (mg/L)	Cell 7 Shale		Cell 12 Alluvium	
		Number of Points	Percent Above Standard	Number of Points	Percent Above Standard
Al	1.0	30	43	29	14
B	0.75	30	30	29	10
Ba	1.0	30	0	29	0
Ca	16.0	30	100	29	86
Cd	0.001	30	13	29	21
Cl	250	9	0	7	0
Co	0.25	30	27	29	3.5
Cr	0.05	30	77	29	17
Cu	0.05	30	17	29	6.9
F	2.0 @ 60°F	30	0	28	0
Fe	0.3	30	0	29	0
K ¹	30	30	87	29	21
Li	0.33	8	0	9	0
Mg	87	30	87	29	0
Mn	0.05	30	67	29	93
Mo	7.0	30	0	29	0
Ni ¹	0.01	29	86	27	63
pH	6.5-8.5	30	0	28	36
SO ₄	250	30	100	28	11
Sr	46	30	0	29	0
TDS	250	30	100	28	32
Ti	0.82	30	3.3	29	0
V	0.15	30	73	29	3.5
Zn	0.1	30	47	29	21

¹Detection limit exceeds criterion value.

phases of the field study. Ba, F, Fe, Mo, Sr, and Ti were generally below the standards for all phases of the investigation. Magnesium was below the standard for the lab studies.

Close examination of the table shows little or no difference between the laboratory and field results in terms of parameters which were consistently above or below the standard. Neither is there a significant difference in the field cells between cells containing disposal media only and cells containing both waste and disposal media.

I.8 References

- I-1. Houle, M.H., and D.E. Long, 1980, "Interpreting Results from Serial Batch Extraction Tests of Wastes in Soils," in Disposal of Hazardous Waste: Proceedings of the Sixth Annual Research Symposium at Chicago, Illinois, EPA-600/9-80-D, p. 60-81.
- I-2. "National Interim Primary Drinking Water Standards," Code of Federal Regulations, Title 40, Part 141.
- I-3. "National Secondary Drinking Water Regulations," Code of Federal Regulations, Title 40, Part 143.
- I-4. RCRA Hazardous Waste Management System, Identification and Listing of Hazardous Waste," Code of Federal Regulations, Title 40, Part 261.
- I-5. Environmental Protection Agency, July 1976, Quality Criteria for Water.
- I-6. Cleland, J.G., and G.L. Kingsbury, Multimedia Environmental Goals for Environmental Assessment, Volumes I and II, November 1977, EPA-600/7-77-136a and -136b, PB-276919 and PB-276920, Research Triangle Institute.